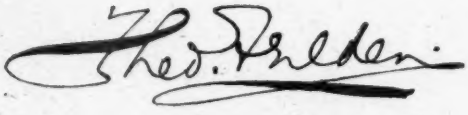
Feilden's Magazine

THE WORLD'S RECORD OF

Industrial Progress.

EDITED BY



VOLUME IV.

JANUARY TO JUNE,

1901.

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NEW CENTURY NUMBER.

FEILDEN'S MAGAZINE.

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The Twentieth Century

ushers in an era of stupendous and unexampled possibilities, an era fraught with more portentous results than probably any preceding epoch in the world's history. What it has in store for us individually and for our country—that great and glorious country which has set a pattern to the world in scientific research, industrial activity and progress—none can tell. But, though none can even vaguely gauge the impenetrable future, one can form reasonable deductions from known facts, and fashion some fairly accurate idea of the fierce, nervy, all-absorbing struggle that is bound to inevitably ensue for industrial supremacy or industrial prestige as time goes on. In the great race that is about to take place Britain will have a hard fight to retain her position. The new condition of things calls for the employment of all her faculties, all her resources, all her skill, all her ingenuity. That the nation which gave birth to Arkwright, Watt, Trevithick, Stephenson, Faraday, Davy, and many others whose illustrious names stand emblazoned on her scroll of fame, will render a good account of herself, no matter what betide, not one of us can doubt ; but let no manufacturer, trader, or business man in this Britain of ours lull himself into any sense of false security. One and all must put their house in order. Those who cannot will most inexorably and unmistakably go to the wall. It is demonstrably evident that in the coming Century the survival of the fittest will be the order of the day, both in regard to individual enterprise and skill and in regard to the general stamina and resources of the country. The race will be more than ever to the fleetest ; the best man will win, conditions being fairly equalised on all counts—and what is wrong in one direction will be balanced up in another.

It might have been a good thing for us as a nation on the dawn of this New Century to have congratulated ourselves upon our impregnability. On the other hand, I am not quite so sure but that the changes which have swept over the industrial horizon during the last twenty or thirty years are not blessings in disguise. The competition that has arisen unchecked, unhampered, among the leading nations of the earth has, at all events, awakened us out of our lethargy to a sense of our responsibilities. Scientific research, industrial and commercial progress and general prosperity have all been advanced a big stage on the journey by the forces that have been called into being by the discoveries and labours of a long line of brilliant Englishmen. The fact that, as was inevitable with the spread of knowledge, we now have strong opponents against us in the industrial race, that we are threatened in the new Century with a competition more assertive, more severe than anything we have experienced in the closing years of the nineteenth, need not give us a set back, but simply urge us on to show that we can rise equal to the occasion. To take serious heed of the vapourings and spread-eagle cries of our commercial antagonists, that the wave of progress which is overspreading the

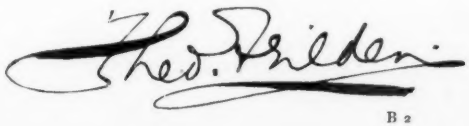
earth portends Britain's industrial extinction, would be to deceive ourselves. At the same time, to assert that we have nothing to fear is just as delusive. We have *everything* to fear because we have everything to conserve, everything to expand. We have simply to look to ourselves—in short, to face the situation, to recognise the power of other progressive nations, and to go one better wherever and whenever possible; in other words, we have one and all to put our finger strongly on the touchstone of that enterprise, skill and endurance which is so characteristic of the British race, and to show the world once more what we are made of.

"A wise man never undervalues his enemies." Hitherto we have in commerce and industry done this, and done it more than once too often, with the result that we have lost markets once wholly and exclusively British, lost prestige, lost trade. Yet we are told by well-informed people that we are busy, busier than we have ever been, and the nation's credit never stood higher. Well, that may be so, but we have lost ground, and are losing ground, simply because we are not advancing at the same rate as other nations, notably America and Germany. That, it may be said, is because they started in the middle of the race, with all the advantages of modern equipment in knowledge and machinery. This is no answer. With our long range of experience, with our big start, with our wealth, resources and world power, we should be able to successfully grapple with this problem, and to progress at least in proportion with, if not to exceed, the efforts of the modern commercial nations. I grant the advantages of the vast natural and practically undeveloped resources of the United States, the Governmental fostering of German industries, the ultra-conservative fiscal policy of this country, and the restrictive tariff arrangements of foreign nations generally. I still maintain we could, and can, hold the lead, simply because the people of this country, and primarily the manufacturers, who form the back-bone thereof and have practically the situation in their hands, could alter many things that are wrong if they would only make up their minds to do so. Drastic diseases require drastic cures, and we shall have to pluck them out root and branch. Our defective Patent Laws, our criminal unconcern in the proper commercial and technical training of our boys, our old-fashioned methods of trading, our Governmental tolerance of the power of the Trade Unions, our grandmotherly legislation in regard to motor traction, our anomalous postal restrictions, our contradictory and absurd freight charges, our unrestricted export of the Nation's best steam fuel to fill the bunkers of foreign men-of-war, our wanton neglect of the methods pursued by our antagonists to secure business, and other glaring inconsistencies, are answerable for much of our comparative non-success to keep the enemy from our preserves. All this will have to be altered in the Century that is before us. A new condition of things has arisen. We must rise to the occasion. If each and every man of this great realm takes this to heart, acts in the living present with all the mental and physical powers with which he is endowed, the future for Great Britain in the comity of nations need not be greatly feared. No insular self-pride must dominate our actions, no self-complacency be allowed to dog our steps, no mental reservation of power be permitted to lag our efforts. Prestige is a great thing: we have attained it in a greater degree than the world has ever witnessed before, but we cannot live on it; we have to face the music of the new score and master it. If it is made manifest to the world that we are doing this, the magnificent loyalty of those great colonies we have formed with brain and muscle in every part of the civilised globe will respond more enthusiastically, more sincerely, than they have ever done during the

national crisis we have just been passing through. In this connection we have the power of making ourselves impregnable, unassailable. The Imperialistic spirit is abroad. That time and "tide in the affairs of men which, taken at the flood, leads on to fortune" was never more conspicuously apparent for Britishers the world over than it is to-day, when we are being assailed on every hand to deprive us of our birthright. All the resources of mankind, all the advantages of civilisation, all the motive power that modern science affords, is at our command. Are we going to set back the hands of civilisation's clock by allowing our rivals to walk over us and steal the fruits from seeds sown with our blood and treasure—seeds which have grown and flourished to the advantage of our race and mankind generally under the beneficent sway of the Union Jack? I appeal to my countrymen, not in any panic-stricken spirit, but in the calm belief in their inherent capacity to overcome every difficulty that the exigencies of circumstances present, to give the lie to the howlings of those ignorant commentators who will not admit that our glorious flag is the harbinger of progress, contentment, and reform, and who aver that we are a decadent nation. In the firm belief that we know where we stand, and *mean* to stand there, I sincerely wish my readers, one and all, a happy New Year and every prosperity in the New Century.

* * * * * * *

Before concluding my remarks, may I be permitted to introduce the personal element as it affects FEILDEN'S MAGAZINE? This journal has, since its inception, persistently and consistently advocated a preference for British-made productions the world over, and has striven to drive in home truths to our manufacturers and traders —some of them not altogether palatable, but, in my humble opinion, none the less necessary. Such a policy has been, and is, the *raison d'être* of our periodical. Needless to say, the efforts of our organisation in these directions will continue with unabated and, if possible, augmented energy. In this connection I hope I am not overstepping the mark as to the merits of FEILDEN'S MAGAZINE when I assert that no small measure of success in the promotion of British trade and industry has attended the labours of those who have been loyally associated with me in the conduct of this journal. It is with the desire to recognise these efforts that I have consented, at the earnest wish of a number of the most prominent supporters of the Magazine, to present on this occasion a portrait group of those who have, more or less, been affiliated with the headquarters staff of the paper from its commencement. The more recent additions are pardonably omitted for obvious reasons, and many of the prominent writers who regularly contribute to our columns have been already portrayed at the head of one of their articles. I may say that I approach this matter with some little diffidence, as, in the accompanying picture, my colleagues have insisted upon conspicuously placing my counterfeit presentment. I appreciate the honour done me in the arrangement of the group, and ask my readers to accept the same as no vain-glorious attempt at personal notoriety, but merely to present them with some souvenir of a memorable epoch in the annals of FEILDEN'S MAGAZINE, which to-day commences its fourth volume, under most auspicious circumstances, with the birth of the New Century.



Is British Trade Declining?

THE attention of the majority of our readers has probably been arrested by the articles from the pen of Mr. Theo. Feilden, Editor-in-chief of this magazine, that appeared recently in the London *Daily Mail* and the *Glasgow Record*. The subject matter of these contributions dealt with a question that has proved, for some time past, a disturbing element in the minds of manufacturers and all concerned in the trade interests of Great Britain, and is one which has frequently been dealt with in the columns of this magazine.

Foreign competition has, during the last forty years, formed a continuous topic of discussion, and even to-day the subject is far from being exhausted. It is asserted by many that a mistake was made when the Great Exhibition of 1851 opened the eyes of the world to our doings, and doubtless there is a certain amount of truth in this contention. The Exhibition, however, even supposing that it was the means of a fillip being given to foreign manufactures, had a compensating advantage in that it showed us how nearly other countries were approaching us in the race. Up to that point Englishmen had lulled themselves in confidence that they alone were able to supply the world, forgetting or ignoring the fact that an advance on the part of other nations in manufacturing was as inevitable as the growth of civilisation.

From small beginnings in the middle-century foreign manufactures have grown to colossal proportions, and more recently at a ratio much greater than that of corresponding home industries.

This relative rate of increase has in recent years prompted the more pessimistic to give expression to views which the more blatant organs of the American press readily construed into evidences of British trade declination and loss of prestige, causing such articles to constantly appear as "England Alarmed at Our Progress," "America Ousting England in the Iron and Steel Markets of the World," etc.

Such dissertations and their analogues in the press of this country have been, generally speaking, of a superficial and exaggerated character, but the imaginative theory of both manufacturing and national decadence which appears to have generated such disquisitions has nevertheless contributed to a feeling that the trade of this country is on the downward grade.

No regular or systematic investigation of the subject, however, has, up to the present, been undertaken, and it was a testimony paid to the rapid success achieved by this magazine when Mr. Alfred Harmsworth, the founder and editor of the *Daily Mail*, actuated by the idea of drawing public attention to the state of trade and national business, approached Mr. Feilden with a view to undertaking an inquiry into the true position of British manufacturing enterprise relative to its two great rival industrial Powers, namely, America and Germany. The results of much time spent both in the examination of statistical records and in interviews with the leading manufacturers of this country were expressed in the articles in a manner which was admitted to be at once concise and impartial, revealing the fact that a condition of stringency in international and industrial competition has arisen, for which past records afford no parallel, and that in certain trades Great Britain is failing to advance at that rate which her position and natural resources would appear to warrant.

Mr. Feilden, in common with other experts, attributes this commercial backwardness to lack of enterprise on the part of manufacturers in being so reluctant to adopt the latest appliances and methods, and a general lack of technical education; and many facts adduced by him also warn us that unless an unsleeping watchfulness be kept on American and Continental business and productive methods an irreparable injury will be done to our trade supremacy.

Signs, however, are not wanting to lead us to believe that the war against apathy, unsatisfactory and superficial as it perhaps has been, has not been without results in

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effecting a stimulus to some portion of Britain's manufacturers, as the adoption of the bonus system and the purchase of up-to-date tools, which are putting the more progressive firms a long way on the road towards attaining an increased output, will testify.

English tool makers themselves have been awakened more particularly by actual stress of foreign competition to the necessity of modernising their products, and the golden harvest reaped by American tool makers in this country for years past, instead of perhaps proving what at first appeared to be a very unfortunate circumstance, may be in a measure condoned in that our own tool makers have been enabled thereby to benefit largely from the American models.

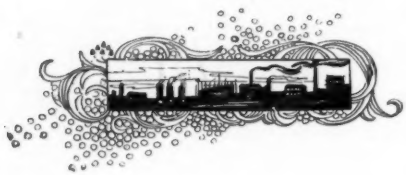
It is felt, however, by the proprietors of this magazine that it is not sufficient to leave the matter at the position reached in the articles contributed to the *Daily Mail*, nor to wholly endorse the views of the writer of the introduction to the series of signed articles appearing in this issue. A special commissioner has therefore been dispatched on behalf of FEILDEN'S MAGAZINE to the chief industrial centres of the United States of America, whose mission it is to render a faithful account of those circumstances of practice which it may be presumed our own manufacturers are not altogether acquainted with.

Among his general instructions, one of the chief is that which relates to the question of comparative productivity; that is, in other terms, the return upon invested manufacturing capital. It may be stated that the industrial product of every hundred pounds invested is very much higher in the United States, where it is the common aim of the men to work every machine up to its highest standard of production, than it is in this country.

It is evident that the question of labour and the conditions of labour prevailing in the United States, compared with the Trades Unions of this country, is an all-important element in this question, and our representative has instructions to give the values, speeds and products of machinery his principal attention.

It is our pleasure to state that in this enterprise we are receiving the co-operation of the *Daily Express*, a journal which has, not only from its establishment, but recently, by the opening of its columns to discussion on the subject of British trade, been distinguished by the vigilant and patriotic attitude it has assumed with regard to British manufactures.

It is to be hoped that the efforts of the joint commissioner may not be without value to the manufacturing community, and that the real nature of the American advance may be proved, once for all, beyond a doubt.



SUP

Supplement to
FEILDEN'S MAGAZINE,
Jan., 1901.

THE BIRTH OF A GIANT.

THE LAUNCH OF THE IMPERIAL JAPANESE BATTLESHIP "MIKASA"; CONSTRUCTED BY MESSRS. VICKERS, SONS & MAXIM, LTD., BARROW-IN-FURNESS.

Our Supplement Plate

this month, reproduced from a clever drawing by Mr. Norman Wilkinson, has more than one feature of interest, not the least being that it is the first plate produced by the unique and expensive three-colour process issued in any engineering monthly journal.

The subject of the picture is the launch of the latest Japanese battleship, *Mikasa*, built by Messrs. Vickers, Sons & Maxim, Ltd., at Barrow-in-Furness. Perhaps the most interesting feature in this vessel is in the distribution of her armour, several modifications in recent practice being apparent. In offering a brief description we, therefore, give first consideration to this. The water-line armour belt extends from end to end, instead of terminating at the ends of the citadel, and thereby leaving about 80 ft. from the stern unprotected. The main belt is 7 ft. 9 ins. wide, of which 5 ft. 3 ins. is under the water-line. The main belt armour protecting the citadel, for 156 ft. in length, is 9 ins. in thickness; beyond this, at either end—to some distance past the forward and aft 12-in. armoured transverse bulkheads—it is 7 ins. in thickness, assisted by additional $1\frac{1}{2}$-in. nickel steel plates placed on the slope of the protective deck, so as to make the resistance equivalent to 9-in. Krupp-Harveyed armour, for the whole length of the citadel and barbettes. From the ends of this 7-in. belt to the ends of the ship the armour is $5\frac{1}{2}$ ins. and 4 ins. in thickness. A 'thwartship bulkhead of 6-in. armour is fitted at the after extremity of the water-line belt to afford protection against raking fire. Above the main armour, and running the whole length of the citadel, there is 6-in. armour up to the level of the upper deck, so that the total width is 21 ft. 6 ins. for the length of the citadel, and 7 ft. 9 ins. forward and abaft it.

The protective deck is of a minimum thickness of 2 ins., and extending the full length of the ship, but it is increased to 3 ins. on the sloping parts within the citadel, and to $4\frac{1}{2}$ ins. in thickness in the wake of the barbettes. In addition, the upper deck within the citadel is made of 1-in. plates. As usual, there is an ammunition passage under the protective deck, with communication, through ammunition tubes, to the various gun positions; while coal bunkers are arranged above and below the protective deck from end to end of the citadel, thus affording increased protection to both the broadsides and ends of the ship.

The general dimensions of the *Mikasa* do not differ materially from those of the British battleships of recent type. The *Mikasa* is 400 ft., the length over all being 432 ft. The breadth moulded is 76 ft. The draught is 27 ft. 2 ins., and at this the displacement will be about 15,200 tons. The *Mikasa's* armament consists of four 12-in. B.L. guns fitted in pairs in the two barbettes and fourteen 6-in. quick-firers, four in the corners of the citadel on the upper deck, and ten in the box batteries on the main deck. The auxiliary armament consists of twenty 12-pounder quick-firing guns, eight 3-pounder quick-firing guns, and four $2\frac{1}{2}$-pounder quick-firing guns, and four submerged torpedo tubes.

The *Mikasa* is to steam 18 knots under natural draught, and will have a coal capacity of 1,400 tons, to give her a radius of 9,000 sea miles at 10 knots speed. The engines are of the triple-expansion 3-cylinder type, the diameters of the cylinders being 31 ins., 50 ins., and 82 ins. respectively, the stroke being 48 ins.; and it is anticipated that 15,000 i.h.p. will be developed with the engines running at 120 revolutions per minute, the steam pressure at the engines being 250 lbs., and at the boilers 300 lbs.

The boilers are of the Belleville type, with economisers. The total heating surface is 37,452 sq. ft., and the grate area 1276 sq. ft. The *Mikasa* will be fitted as a flagship, accommodation being provided for an admiral and 78 officers, the total complement being 935 all told.

Scientific and Industrial Chronology of the Century.

1800 Electric light obtained with carbon points by Sir Humphry Davy.
1801 First railway sanctioned by Parliament and worked by horses run between Wandsworth and Croydon.
Symington's first steam-boat experiment on the Thames.
1802 Trevithick's and Vivian's patent for high-pressure locomotive engine.
1807 Street-lighting by gas introduced to London at Golden Lane.
1808 Dalton's atomic theory published.
Life-saving rocket apparatus invented by Capt. Manby.
Polarisation of light by refraction.
1811 Sir W. Herschel's nebular hypothesis published.
1812 First steam-boat, *The Comet*, sailed from Glasgow to Greenock three times weekly.
Blenkinsop's engine first used.
1813 "Puffing Billy" built and used on the Wylam railroad.
Niépce first obtained a permanent sun picture.
Davy exhibited the voltaic arc.
1814 Stephenson's first locomotive built for the Killingworth Colliery.
Steam power first applied to printing in the *Times* office.
1815 Invention of the "Davy" and "Geordy" safety-lamps.
1817 Waterloo Bridge opened.
1818 The *Rising Sun*, a steam vessel, crossed the Atlantic.
1819 Oersted's discovery of electro-magnetism.
Southwark Bridge completed.
James Watt died (Aug. 19).
1821 Steamboats established between Dover and Calais.
1824 Lord Kelvin born.
1825 First railway opened for passenger traffic between Stockton and Darlington.
First steam voyage made to India by the *Enterprise*.
1827 Laplace died (March 5).
1829 George Stephenson's "Rocket" gained the prize of £500 offered by the directors of the Liverpool and Manchester Railway.
Sir Humphry Davy died (May 29).
1830 Opening of the Liverpool and Manchester Railway.
Faraday's discovery of magneto-electricity.
Lippman succeeded in photographing the solar spectrum in its natural colours.
1831 London Bridge opened.
1832 Sir David Brewster's discovery that the vapour of certain gases was represented in the spectrum by characteristic dark lines.
1834 Sir W. H. Preece born.
Thomas Telford died.
1837 Screw steamer *Francis Bogden* constructed by Ericsson.
First railroad in France opened from Paris to St. Germains.
Wheatstone and Cooke's first electric telegraph.
1838 Telegraph set up between Paddington and West Drayton on the Great Western Railway.
Great Western Railway opened to Slough.
London and Birmingham Railway opened throughout.
Regular steamboat communication established across the Atlantic.
1840 First Cunard steamer, *Britannia*, made her voyage across the Atlantic.
Telegraph adopted on the Blackwall Railway.
The first atmospheric railway opened at Wormwood Scrubs.
1841 Great Western Railway opened to Bristol.
1842 "Correlation of Physical Forces" (Sir W. Grove) published.
1844 Co-operative movement founded in Rochdale.
First Factory Act passed under that name.
John Dalton died (July 27).
Morse system adopted between Baltimore and Washington.
1845 The gauge of the Eastern Counties Railway converted from 5 ft. to 4 ft. 8½ ins.
1846 Railway mania and panic. 272 Railway Acts passed.
1848 The South Devon atmospheric railway opened.
George Stephenson died.
High Level Bridge, Newcastle, opened by the Queen.
1850 The first train passed through the Britannia Bridge.
Robert Stephenson died (July 12).
1851 First submarine cable laid between Dover and Cape Grisnez.
1851 Great Exhibition opened in London.
1853 First Warren girder bridge (Newark Dyke) opened.
1854 Ohm died (July 6).
1855 Bessemer steel process patented.
1856 Duboscq's electric lamp used by Professor Tyndall at Royal Institution.
1857 Commencement of the laying of the cable between Valencia, Ireland, and Newfoundland.
Crumlin viaduct completed.
1858 First telegraphic message across the Atlantic.
1859 I. K. Brunel died (Sept. 15).
Royal Albert Bridge, Saltash, opened.
Darwin's "Origin of Species" published.
1860 Launch of the first ironclad built by the Government and propelled by steam.
1863 Double screws used on the *Far East*.
Opening of the Metropolitan Railway.
1865 Wilde's dynamo electric machine invented.
Indo-European Telegraph opened.
1866 Cable between Valencia and Newfoundland successfully laid by the *Great Eastern* steamship.
1867 Siemens' dynamo introduced.
International Exhibition at Paris.
Michael Faraday died (Aug. 25).
1868 First section of the Great Western broad gauge converted to narrow gauge.
Post Office acquire the Inland Telegraph.
1869 Suez Canal opened.
Blackfriars Bridge opened.
Completion of the Pacific Railway, uniting New York and San Francisco.
1870 Mont Cenis tunnel completed.
1871 Darwin's "Descent of Man" published.
1875 Gramme's dynamo introduced.
Wheatstone died.
1876 Direct cable communication between London and New Zealand first established.
1877 Bell's telephone first tried in the United States.
1878 Jablochkoff's electric candle came into use.
1879 Collapse of the Tay Bridge.
Clerk-Maxwell died (Oct. 19).
1880 Electric lighting introduced on the Thames Embankment.
St. Gothard tunnel pierced.
1881 The "Swan" lamp used in the Savoy Theatre.
1882 Electric energy derived from accumulators used as a motive power for tramcars at Leytonstone.
1883 Electric tramcars in London (Kew to Hammersmith).
1885 Maxim machine gun described in *Nature*.
1886 The *Volta* electric launch crossed from Dover to Calais.
Opening of the Mersey tunnel.
1888 Severn tunnel opened for traffic.
Through railway communication to Constantinople.
1889 Electric omnibuses run in London.
Joule, the discoverer of the "mechanical equivalent of heat," died (Oct. 11).
1890 City and South London Electric Railway opened.
1891 Queen Victoria Street permanently lighted by electric lamps.
Electric transmission adopted between the Rapids of Neckar and Frankfurt.
Opening of the Forth Bridge.
1892 Niagara Falls utilised for the production of electricity.
The whole of the broad gauge lines of the Great Western converted to narrow gauge.
1893 Opening of Liverpool Overhead Electric Railway.
Solidification of air by Prof. Dewar.
1894 Manchester Ship Canal opened.
1895 Discovery of the X Rays by Dr. Röntgen.
Baltic and South Sea Canal opened.
1896 Motor carriage race to Brighton.
1898 Opening of the Waterloo and City Electric Railway.
Sir John Fowler died.
1899 First number of FEILDEN'S MAGAZINE published (August).
Opening of the Great Central extension to London.
21,700 miles of railways open in the United Kingdom, carrying 1,106,691,991 passengers, with total receipts £95,851,393.
Wireless telegraphy succeeded between the French and English coasts.
1900 Central London Electric Railway opened.
Australian Commonwealth formed.
Death of Lord Armstrong (Dec. 27).

A Century of Science, Engineering, Manufacturing and Trade.

"We set foot in a field that is crowded by thinkers, men whose restless spirits seek ever to set the confines of the known further and further forward!"

❀ ❀ ❀

Introductory.

EVEN the most obscure thinker, should he ponder over the remarkable events that have taken place during the past ten years in the development of scientific knowledge, must look forward with wonder, and perhaps some disquietude, to what may await him during the course of the new century.

Certainly we are becoming inured to scientific miracles, and what would have greatly excited and perhaps horrified our forefathers is accepted by their descendants almost as a matter of course. Wisdom is certainly not a monopoly of the present generation; but it is greatly to be questioned whether the collective sagacity of the nation even at the time when this was supposed to have attained its zenith would have prevented a predominant number of the prevailing practitioners of science from suffering a fate which was decreed to those who practised unholy arts. It is humanly certain that Edison himself would have been pointed at with the finger of suspicion in Puritan days, and his apparatus looked on in the light of a sort of devil's laboratory, to be eschewed by all honest people. Men at first, restrained by superstitious fears, refused knowledge; gradually they came to accept it with limitations, dreading the draught of life, receiving it with fear and hesitation. At the present day we find the field of knowledge so illimitable, that its only measure is our own capacity to receive it. We know that we live among unknown and prodigious forces, whose nature and extent is, at present, mystery. We know that our earth is no mere isolated unit among the worlds, but that the infinite bounds of space are filled with some perplexing, inscrutable medium that binds and associates all forms of matter in one all-pervading homogeneity. We know that light, heat, electricity, and magnetism are probably only different manifestations of a medium which we have agreed for the time to call "ether."

Science ever creates more mysteries than she solves. Ever active, ever working, she sees the boundaries of knowledge constantly recede as she approaches them, revealing strange, enchanting prospects, half hidden from the view by overhanging mists through which her light is dimly penetrating.

The nineteenth century will be looked upon as that epoch of the world in which the rise and progress of the Peaceful Arts will in a great degree displace the ordinary materials for historic research.

"History," said Hume, "is little more

than a recital of the crimes, follies, and misfortunes of mankind."

It is true that when we survey the records of past ages we find little in the general conditions of human existence to distinguish one century over another. Of progress, as we now understand the term, there is scarcely any to be seen. We look back upon century after century, brooded over by superstition and ignorance, whose chronicle is one gloomy uniformity, only illumined here and there by the sinister glare of battle and slaughter on some more than common scale. Over these dark ages, the century that has just passed away rises like some glorious transformation scene, replete with light and hope to the higher humanity. Future chroniclers will find the influences that guide human conduct and mould human character flowing not, as in the past, chiefly from the statesman and soldier, but from the scientist and engineer. Knowledge without intercourse is of but little value. The art of printing, for instance, has been existent for hundreds of years, but it little influenced the spread of education till the engineer and mechanician stepped forward with the means by which it might be utilised by the masses. The world is usually sparing in its rewards to those to whom it is most indebted: it overwhelms its warriors with wealth and honours, and leaves its peaceful geniuses to pine in obscurity and die in poverty. Such, at least, was the usual reward of conquerors in physical research in the dark days of the past. Now more liberal ideas prevail in the rising generation, and the glories of a knighthood may possibly illustrate the merits of some scientist or inventor who is instrumental in changing the destinies of half the human race.

The resources of science are self-multiplying: what may we look forward to in the next fifty, even twenty, years? The most fervent imagination may well be staggered in the attempt to contemplate the prospect that lies before us, in the light of the achievements that have been crowded of late into such a narrow space of time.

Though the delicate fingers of the scientist will displace the horny hand of the son of toil and bodily labour in all manufacturing processes become extinct, it is to the rough artisanship of humble labour in the early century that the present-day evolution in manufactures and inter-communication is due. That there is some kind of law of evolution in science and mechanics, as well as in the animal and vegetable worlds, appears certain; though whether in the former case the times produce the inventor, or the inventor the times, is not so clearly made out. It seems probable, however, that had James Watt never existed we should have not had to wait for the steam-engine very long; nor would the steam locomotive have been lost to the world in the absence of either Trevithick or Stephenson. There appears a spontaneity of idea associated with nearly all organic invention which is most interesting to note. It would seem as if invention, like seed, lies germinating in hidden places, and begins to sprout only at the approach of harvest time. Watt's inventive genius, in any case, was the cause of the great industrial harvest in England, which gave the country that lead over its rivals in the world it now seems in danger of losing. It opened the coal mines, and set ablaze the iron furnaces of the North of England; caused great areas of manufacturing buildings to arise, throbbing with ceaseless activity; threw a net-work of iron throughout the highways and byways of the world and the manifold outlets of this growing industrial organism, gave rise to that commercial supremacy which it is England's fading boast to hold to-day. It appears, also, to have inspired an aggressive activity of thought we do not appear to possess with the same force at the present time, for in the early and middle portions of the nineteenth century England was the leader of the world. She gave it steam power, steam locomotion, steam navigation; she provided it with telegraphs, submarine cables, and set the example of a postal system of singular daring and originality. England, too, startled the world by inaugurating a system of Free Trade, the greatest and boldest step ever made in economics, and brought her policy to a practical

success in face of the menacing prophecy of a host of home and foreign critics.

Of late years England has not maintained her position as the chief performer in the world's arena. She seems to have lost, or at least become temporarily deprived of, that faculty of initiative that in the past has been of such signal service to the nation. It is certain she no longer shines in any department of human affairs with such brilliance as before—no longer occupies the proud, commanding place among the nations which was her unquestioned right but a few short years ago. In science and the mechanical arts we look to foreign rather than to British guidance. The most famous workers in the world of science and the inventive arts must be sought beyond our shores.

How is it, then, that with one or two qualified exceptions, the British as a manufacturing and commercial nation are retrograding so rapidly, drifting so visibly toward the rear? In what art or manufacture, except, perhaps, that of shipbuilding, are we entitled to be considered supreme in the sense of thirty years ago? It is true that those who regard the signs of English decadence with incredulity point triumphantly to the inflated current of imports and exports, and ask how it is possible to reconcile these constantly increasing values with national retrogression. The figures do certainly show that as a mercantile nation we are not declining, though it is to be noted that in the period of prosperity which has visited the great commercial nations our advance has been alarmingly disproportionate, and altogether inferior to the phenomenal progress made during the same period by our rivals. A nation that depends even partially for its material prosperity on affording a mart for the exchange of commodities stands on no stable foundation. Its producing power is the true measure of a nation's standard of existence, and as its producing power is high or low it takes its position accordingly.

We have seen recently the spectacle of England, the land to which steam-power owes its birth, being compelled to import steam-engines for her own use over three thousand miles of sea. In ocean navigation the "mother of the seas" has retired to a second place in the speed records of the Atlantic, and suffered a country whose name at one time was a term of derision in association with its manufactures to usurp the position attained by our forefathers. In land locomotion the country that first gave rise to the motor-car looks for instruction across the English Channel, and notes the railway records it is unable to rival achieved in a land whose railways were planned by British engineers and laid by British labour.

Let us look back over the past twenty years. During that period an enormous evolution has taken place in Science and Mechanics. The subtle force represented by electricity has been mastered and placed under human control. A new era has been opened up in industrial chemistry, and the electric furnace has given a new aspect to metallurgy; the electric current is now being used for power, light, and heat. Yet in none of the developments which have placed electricity as an industrial force on a level with steam itself do we find England in the front; she is not even in the second place. Sir Humphry Davy discovered the electric arc, but the electric arc lamp has been devised abroad; of the names of Brush, Weston, Thomson, and Houston, none of them denote British citizenship. William M. Grove evolved the first electrical incandescent lamp; until a few years ago the supply of electric glow-lamps was an American monopoly associated with the names of Edison and Swan.

Of the more notable inventions made during twenty years past, hardly one can make a claim to British parentage. The Hoe printing press; the Westinghouse brake—Edison, Graham Bell, Pictet, Otto, the typewriting machine, Siemens, Faure, the telephone, the phonograph, the linotype machine, the commercial production of aluminium, von Welsbach, Elihu Thomson, armour-plate annealing, Chardonnet, Moissan, Willson, calcic carbide and carborundum, Röntgen, Linde, Marconi—not one of these can be ascribed to this country. During the whole of this period, in fact, the only English invention of more than local importance is the

Parsons steam turbine, a machine, however, very closely approximated to by that of de Laval.

This period of intellectual stagnancy in the arts and sciences may be compensated for later on by some signal revival of the spirit which distinguished England in the mid-century; but it is not possible to disown the fact that the honours in invention and industrial development have for the time at least passed from this country to the United States and Germany.

When England abolished her Customs dues, retaining only a sufficient tariff to provide a revenue, it was assumed by the disciples of Cobden and Bright that no country whose native industries were not protected from competition by prohibitive duties could ever hope to compete successfully with this country in neutral markets.

Many contemporaries of these great statesmen have lived to see the utter falsification of their cherished convictions. Confident as they were of securing the world as a permanent market for English manufactured products, they little expected to see the time when England would be threatened with destructive trade competition within her own shores from the very countries which she had appropriated in anticipation as abiding customers for her own manufactures.

The seriousness of the foreign competition we are now experiencing, and more especially that we may surely look forward to, cannot be over-estimated. The foundation of all producing industries is necessarily that of iron. A few years ago, England, supreme in production as she still is in commerce, produced far more pig-iron than any other country. Last year, the United States usurped that position, and England had to be contented, perforce, with a second place. In the manufacture of steel, England's place is still worse; she has fallen from the first place to the third, being now actually behind Germany.

In America, that country of colossal possibilities, manufacturers have found that the chief effective agent in the manufacture of low-priced products is not so much the cheapness of the raw material as the methods employed in production. They have found that the greatest economies are associated with the largest outputs, and in American works the rule is that all other questions are subordinate to that of the rapidity with which the different operations of manufacture are carried out. This necessarily infers a constantly increasing scale of production. All improvements in machines or methods tend toward the rapidity with which, either in time or in quantity, the output of the works can be accomplished, for the manufacturer is aware that the more he extracts from his machinery within a given time the less he expends on the fixed charges, rent, interest, etc., which form one of the principal burdens on a large manufactory.

The inevitable consequence is that in time the home market becomes over-supplied with home products, and the manufacturer finds increasing difficulty in obtaining purchasers for his productions. His only immediate resource consists in cheapening his wares to such a degree that they may secure a sale preference over those of his competitors; and in order to do this, and yet make a profit to himself, the brains of countless mechanicians are on the rack for improvements in machinery or processes, by which *time*, the all-important factor, may be saved in production.

England has not been subjected to the stress of interior competition in the same degree as the United States. Her manufacturers, indeed, do not compete at all, if we compare the course of home English trade with the ferocity that marks American trade rivalry, which is content with not less than the effacement of a trade adversary. As a very large proportion of English manufactured products are made expressly for export consumption, the stress of competition has prevailed mostly among merchants and shippers, and the competition has been between themselves for the best terms from the manufacturer, who has never altogether lost the position of an arbiter in the question.

America now finds, however, that it is a matter of vital consequence to her future to build up a great export trade that

may provide an outlet channel for her constantly augmenting productive resources. Her manufacturers have already gone through an internecine strife, and the survivors emerged equipped to carry on the struggle for existence with weapons our own manufacturers, until late, have never felt the necessity of. The system of automatic machinery, such quantities of which have come to us from the United States, has been carried to a pitch of perfection never even, save in isolated instances, contemplated in this country; and although the capital employed may be larger, the materials more expensive, and the labour more costly, yet the total output within a given time is so large that the cost of each completed article may be considerably less than in even the best-equipped existing British works of a similar description.

How under such circumstances can English manufacturers hope to compete in neutral markets with their American rivals, unless some radical change is made in British manufacturers' methods? Already they have found their incompetence to do so demonstrated by several striking illustrations. It is time that manufacturers, workmen, shippers and agents should take the position into their most serious consideration.

It is not my object to attempt to render this short and very imperfect article striking by the employment of sensational pessimism. I will only ask this question: Consider the progress the United States —the competitor we have most to dread —has made during the past ten years, and compare it with our own. Is there any reasonable man who will venture to express the opinion that the advance of the United States, extraordinary as it has been during that time, is likely to be retarded within the *next* ten years? And seeing that progress in manufactures, as in many other relations, is cumulative, is it not possible, and even probable, that the progress of the American States may in the future be even more rapid than in the past?

Then, in that case, where will England be?

We must remember that the world now affords little elbow room to those who occupy it. It is not possible for one great nation to grow, save at the expense of its neighbours. England stands like a corpulent tradesman amid a crowd of hungry rivals: and in the remorseless competition that is the inevitable fate of the civilised world it will be England that will be squeezed. England has gained more, and has more to part with, than any other nation. She can hardly hope to advance materially, under present circumstances, on her existing position. Let her, therefore, make every preparation—not by any means that of guns and warships, but by education, training, and enterprise—to keep what she has got.

A cry, at present feeble, almost inaudible, is already being made in some obscure quarters—I notice it in several papers associated with South Africa—for a reversion to the old system of Protection. Free Trade is either a cult or a policy, according to the views of its supporters. I am by no means a bigoted adherent to Free Trade as a policy, though as a doctrine I may admit without examination the merits of a theory that has little chance of being carried into general practice. But although one may not care to blindly confide in the sacro-sanctity of Free Trade and adopt it as a secular religion, it does not follow that he is to fall at once into the disordered ranks of Protection.

The truth appears to me that Protection may at once be a safeguard to youth and a refuge to senility. We support with artificial aid the growing plant and the falling tree. Young nations require Protection to guard their tender industries; old ones to preserve them. But who will dare to say that England is deprived of the vitality of its youth, and not fit and able, and ready too, to fight for her possessions in the world of commerce and industry as desperately as she has ever done in the battlefield?

Many things require to be done, many prepossessions abandoned, many sacrifices made. Chief among all, and among all most painful to be endured, is the necessity of acknowledging freely and unreservedly that we are being beaten; not by

any combination of circumstances that takes away our responsibility, but because we deserve to be beaten; because our rivals, for a time, are the better men. If we freely, spontaneously accept this position, without waiting to have it demonstrated upon us in a more sensational manner, we shall have taken the first great step to retrieve the ground we have lost. We must amend our sluggish ways of manufacture. The value of the output for every hundred pounds of sunk capital must be vastly increased. The Trades Unions are a curse to themselves and the country. Their influence is almost wholly pernicious. They stifle character, stultify development, and inculcate immorality. They are a natural development of the spirit that led to the destruction of machinery in the early century, and are effecting the same ends. Most of their members are staunch "Free-Traders," though they apply "Protection" to their own labours. Their attitude is natural enough, though mischievous, and likely, if persevered in, to be disastrous. They are banded against what they consider would become the encroaching spirit of the employers should they be disunited. Their object, then, is to obtain work and a certain wage for all their members; and it necessarily follows that in its fulfilment the lazy, the unfit, and the dishonest workers must be given the same position as the honest and proficient. Besides, economy of production attained by the employment of economical machinery is necessarily obnoxious to this artificial factor in manufacturing economy, and its powers frustrated and curtailed as far as possible. It is this attitude, and not the minimum wage, that is objected to by all enlightened employers, who already foresee the necessity, for their own self-preservation, of freeing themselves from the incubus thus laid on them.

There are signs here and there—not ostentatious, for the typical English manufacturer makes little parade—that the lessons opened to us of late have not passed unread or unacted on. British character, however, moves slowly. Like some ponderous locomotive, its start is slow, almost imperceptible. Yet it gradually gathers way, increasing and increasing, till it attains its speed and a momentum, that drives it irresistibly through all obstacles.

INVESTIGATOR.

Men, my brothers, men the workers, ever reaping something new.
That which they have done but earnest of the things that they shall do.
Not in vain the distance beacons. Forward, forward let us range,
Let the great world spin for ever down the ringing grooves of change.

TENNYSON.

The Development of Mechanical Engineering.

By W. N. TWELVETREES, M.I.Mech.E.

GREAT as our faith may be in the possibilities of science, it is difficult to conceive that any future epoch should present a more remarkable record than that of the century which has recently drawn to a close. And yet, although the veil has been drawn further aside from many hidden laws of Nature, and the ingenuity of man has lighted upon many cunning devices by whose aid these immutable laws have been utilised, it must not be forgotten that many of the discoveries and inventions more particularly associated with the Nineteenth Century were distinctly foreshadowed, and to some extent realised, by profound thinkers and practical men in earlier days. So far as relates to mechanical engineering, it may, perhaps, be said that much of the work done in the past century has comprised the development of ideas partly grasped in earlier times, and the perfection of appliances fairly correct in theory but deficient as judged from a practical standpoint.

At the period with which our present review commences, the steam engine, of which the prototype had been suggested some nineteen hundred years before, was already an accomplished fact.

Newcomen's engines were the first to be used with practical success, and although most of them were displaced by the improved engines introduced by Watt, at least two examples have survived until the present day. One of these is at the Ashton Colliery, Lancashire, and the other at the South Liberty Colliery, Long Ashton, Bristol. The engine at the latter place is illustrated by the two drawings in Fig. 1, and up to a recent date it was employed for pumping water, having been used for the same purpose during a period of 150 years. The engine is known locally as "The Old Lady," and the old man until recently tending this engine inherited the post from his father, who likewise succeeded his father as the driver of this historic relic, which forms so interesting a link between the eighteenth and the twentieth centuries.

The attention of Watt was directed to the subject of steam-engines soon after his appointment to the position of mathematical instrument maker to the University of Glasgow in 1757. By adopting the separate condenser and the air pump, Watt obtained conditions which had hitherto been considered impossible — a hot cylinder and a perfect vacuum. But he decided to go a step further, and to make steam instead of atmospheric pressure the motive power. After a somewhat unfortunate partnership with Dr. Roebuck, the founder of the Carron Ironworks, Watt became associated with Matthew Boulton, at the Soho Works, Birmingham. There he introduced various improvements, including the sun-and-planet motion, the double-acting principle, the use of the expansive force of steam, the parallel motion, and the governor. The sun-and-planet motion, of which an illustration is given in Fig. 2, was introduced as an alternative to the crank, which was at that time claimed by a rival patentee.

In Fig. 3, is reproduced the photograph of an engine in the possession of the Birmingham Canal Navagations. This pumping engine is the only existing one of the first two built by Boulton & Watt in 1776, and in the order book of the firm for that year it is described as a single-acting beam engine, with chains at each end of a wood beam, and having a cylinder of 32 ins. diameter with a stroke of 8 ft. James Watt not only designed the engine but prepared the drawings, and it was

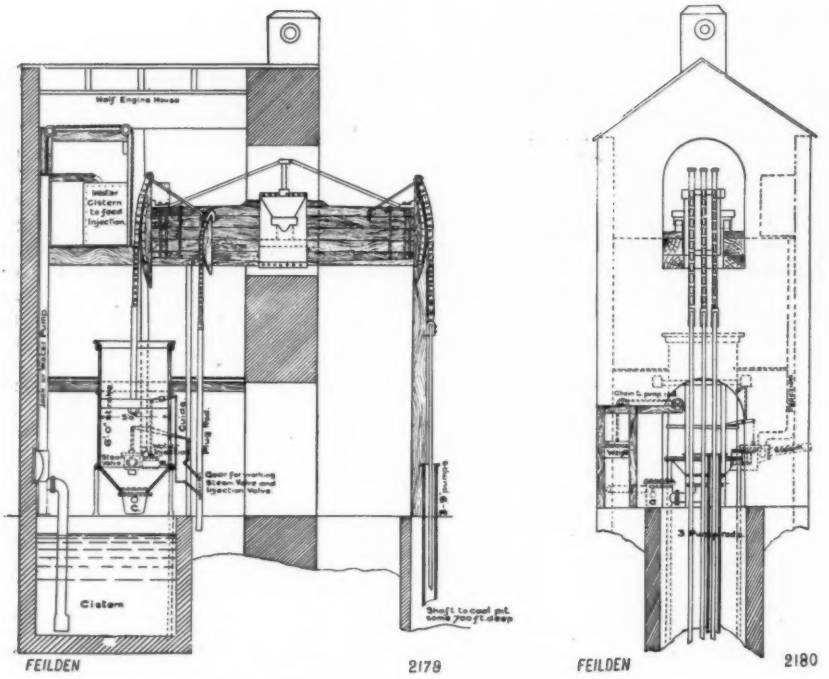


FIG. 1.—NEWCOMEN ENGINE AT THE SOUTH LIBERTY COLLIERY, LONG ASHTON, BRISTOL (ERECTED ABOUT 1750).
(From drawings furnished by H. W. Pearson, Esq., M.Inst.C.E., M.I.Mech.E.)

made under his supervision. Having been in use for about 120 years, the engine was removed in 1898 to the Canal Station at Tipton, where it is preserved as a monument of early engineering skill and sound workmanship. It is interesting to record the fact that in 1898, the Canal Company ordered from the same firm, James Watt & Co., of Soho, two modern vertical triple-expansion Corliss surface-condensing deep-well pumping engines, which have since been installed at the Walsall Pumping Station.

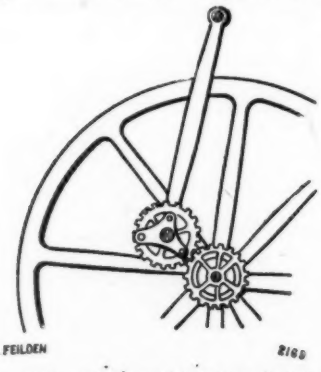


FIG. 2.—WATT'S SUN-AND-PLANET MOTION.
(From an old woodcut.)

It will be seen that even on the eve of the Nineteenth Century, iron was by no means regarded as an essential material of construction. In later types, however, the beam was made of cast iron, although timber was still employed for parts of the framework. Before the time of Watt, the steam engine was merely a pump, a slow-working, relatively weak, and cumbrous apparatus, wasteful of fuel to the last degree. By his first patent, Watt gave

FIG. 3.—PUMPING ENGINE, BUILT BY BOULTON AND WATT IN 1776.
(From a photograph lent by James Watt & Co., Soho Foundry.)

to the world a quick-acting, powerful, and economical engine, but still only suitable for pumping purposes. The later improvements, to which reference has been made, extended the scope of the steam engine, and made it available for general use.

In the year 1801 the first high-pressure engine using steam at three or four atmospheres was invented by Oliver Evans, an American millwright. The quaint illustration in Fig. 4 is reproduced from an old woodcut, and gives a general idea of the engine and steam generator.

Just about the beginning of the century, two gas engines were introduced in which many modern ideas were incorporated. In the first of these, invented by Robert Street, inflammable gas was exploded in a cylinder, driving up the piston by expansion, and forcing down the piston of a pump for lifting water. This engine exemplified the principle of internal combustion, ignition by external flame, and the inward suction of air during the up stroke of the piston.

The second was patented by a French engineer named Lebon. His engine was double-acting, the inflammable gas and sufficient air for ignition were introduced into the cylinder on both sides of the piston, and the inventor proposed to fire the mixture by means of an electric spark.

The notion of propelling vessels by steam power was entertained in the eighteenth century, but it was not until the improvements of Watt and others had prepared the way that any successful trial was made. The earliest of these appears to have been that of Symington, in the year 1801.

Oliver Evans conceived the idea of a steamboat, and also of a steam wagon, as early as 1785. In 1786 a committee of the Pennsylvanian Legislature heard a petition from Evans "very patiently," when he described his mill improvements; but his representations concerning steam wagons made them think him insane.

In the early days of the steam engine, boilers were made of cast-iron or copper; but when higher pressures began to be used, the employment of wrought-iron became common, as being cheaper than copper and safer than cast-iron. Previous to the time of Watt, steam boilers had generally been of cylindrical form, for the sake of

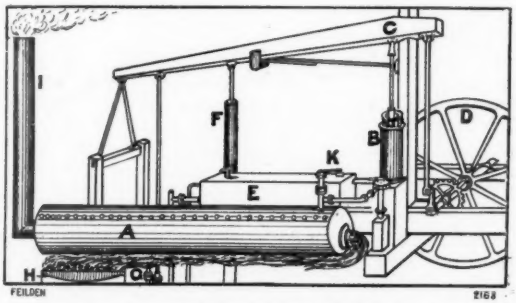


FIG. 4.—OLIVER EVANS' HIGH-PRESSURE ENGINE. (THE FIRST AMERICAN STEAM ENGINE, 1801.)
(From an old woodcut.)

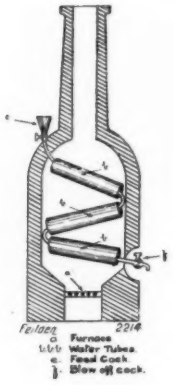


FIG. 5.—BLAKEY'S STEAM BOILER (PATENTED 1766).

strength; but the "wagon" type was then introduced with the view of increasing the amount of heating surface. The boiler shown in the illustration of Oliver Evans's engine was probably one of the first examples of an internally-fired boiler.

A patent obtained in 1766 by Blakey, foreshadowed the water-tube boiler. As will be seen from Fig. 5, the generator was a very crude affair, but it is interesting, as showing that essential principles were correctly appreciated a long time ago.

Several early attempts were made in the direction of smoke prevention; but the improved furnace of John and James Robertson, of Glasgow, appears to have been the first which was economically successful.

Early engine-builders suffered so much from the want of proper tools, that Smeaton said the steam engine was doomed to failure, because he considered its working parts could never be made with the requisite accuracy.

A machine designed by Smeaton for boring cannon at the Carron Ironworks was not found particularly satisfactory when applied in the construction of steam engines. Watt complained that a cylinder bored in this machine was so much out of truth that a difference of $\frac{3}{8}$ in. occurred between the diameter at one place and that at another. As the mean internal diameter was only 18 ins., it is not surprising that the piston did not prove to be steam-tight, notwithstanding the addition of a packing comprising "paper, cork, putty, pasteboard, and old hat." Fig. 6 is the section of a piston showing the method adopted before the advent of metallic packing. Barton's improved piston, patented in 1818, was largely used by Maudslay, Hall & Son, of Dartford, and others. It was also adopted in the United States, being known there as Browne's piston, after the name of the engineer who pirated the idea.

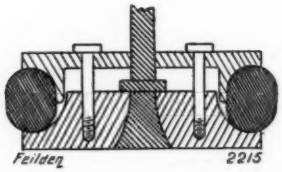


FIG. 6.—SECTION OF PISTON PACKED WITH HEMP (OLD STYLE).

The boring bar devised by John Wilkinson in 1775 forms the basis of the boring machine as used in the present day. Before the introduction of this appliance, in which the bar was supported at each end, the tool was free to deviate in accordance with the eccentricities of the internal surface.

The lathe, it is true, had been in existence for many centuries, in the form of the "dead-centre" lathe, worked by means of a treadle, cord, and spring-lath. For heavy work, the spring-lath was first supplanted by a separate fly-wheel, and next by a fly-wheel actuated by a treadle and crank. The headstock took the place of the dead-centre, and iron gradually took the place of wood for the frame, but the lathe could not properly be regarded as a tool of even moderate precision until the slide-rest had been added.

It appears that the slide-rest was used in France as early as the year 1772, but it was unknown in England until re-invented in 1794 by Henry Maudslay, then employed as a mechanic by Joseph Bramah, of Pimlico, London. For the purpose of demonstrating in what condition the art of turning was just before the commencement of last century, we may usefully quote the

following passage from a report by Mr. Bramah on Watt's engine specification. Speaking of the piston-rod, he says: "I am certain, from my own knowledge, that Mr. Watt, in his first outset on this business, found more difficulty in procuring these rods in all respects perfect than he would have done in constructing all the parts of Newcomen's engine."

Plane surfaces had to be finished in early days by chipping and filing. This and other kinds of special work were performed in Watt's workshops by men who were so carefully trained as to acquire wonderful proficiency, although they could not ensure the mathematical accuracy which characterises work turned out by modern tools.

Forgings of any great size were not required in those days, and hammermen could deal without difficulty with such forged parts as might be wanted for the steam engine. Heavier forgings were shaped by an appliance known as the "Hercules," in which a mass of iron working in vertical guides was raised by a gang of men with ropes and allowed to fall, after the manner of a pile-driver.

Power transmission, in the early part of the century, was an almost unheard-of luxury, except to the limited extent permitted by the timber shafts, or "gudgeon" and "trundle-wheels" of the millwright.

Bramah obtained patents covering the distribution of power by hydraulic means, and also by compressed air, but neither of these excellent ideas were destined to be fully worked out until comparatively recent times. It appears, however, that as early as 1802 Bramah applied the hydrostatic press to cranes for hoisting merchandise, and afterwards to tools in his own workshops.

Henry Maudslay appears to have started in business soon after the year 1800, for it is recorded that in 1807 he was engaged in erecting what would be described in the United States as a complete "outfit" of wood-working machinery for making ships' blocks in Portsmouth Dockyard.

Clement was another workman employed by Bramah, and he is one of those to whom the invention of the planing-machine is ascribed. Clement afterwards started in business upon his own account, and soon became celebrated as an ingenious mechanician, especially in connection with machine tools, for which he received several awards from the Society

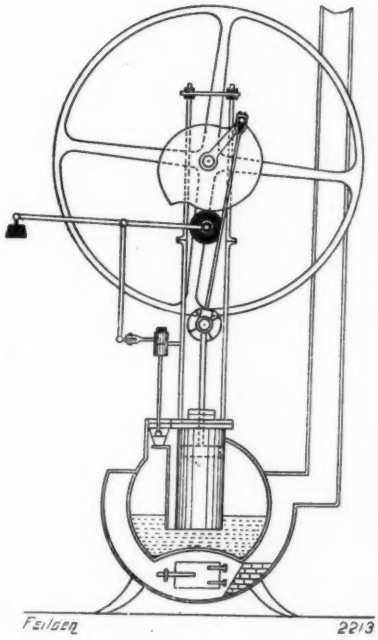


FIG. 7.—TREVITHICK AND VIVIAN'S HIGH-PRESSURE STEAM ENGINE (PATENTED 1802).

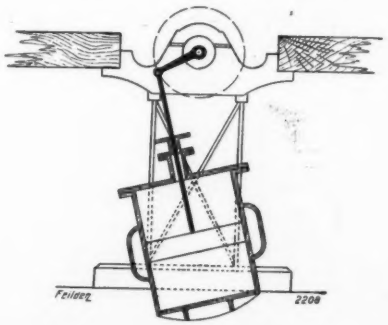


FIG. 8.—DIAGRAM OF OSCILLATING ENGINE.

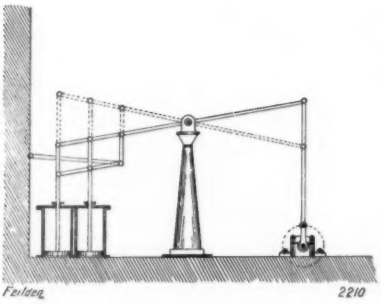


FIG. 9.—DIAGRAM OF WOLFF'S COMPOUND ENGINE (A.D. 1804).

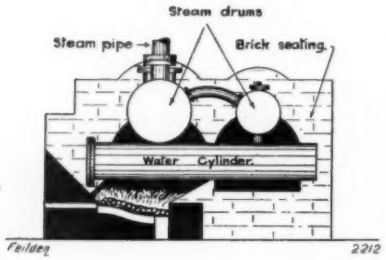
of Arts. Before the year 1820 he constructed a planing-machine on a small scale, but he afterwards made a larger one, which for many years was the only good machine of its kind, at any rate, in London.

It may be doubted whether the planing-machine could be relied upon at that time to do more than produce a comparatively plane surface; for many years later scraping was still recognised as the only means of bringing the metal to a commercially true plane. As a survival of the latter process, the practice was followed of scraping certain parts of machines without any apparent object except that of impressing the purchaser. It is to be feared that this kind of imitation work, characterised by the late William B. Bement, of Philadelphia, "bedquilt scraping" has not even yet been entirely abandoned.

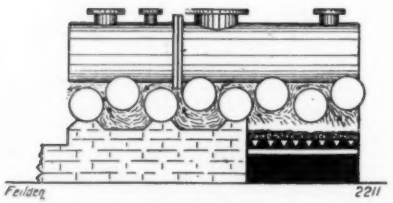
The three improvements already noticed, the boring-bar, the slide-rest, and the planing-machine, were sufficient to revolutionise mechanical art, and to diminish appreciably the difficulties under which early engine-builders laboured. But a good deal remained to be done before machine tools reached the stage of development necessary for the satisfactory and economical performance of work. Maudslay and Clement continued their efforts not only to produce better tools, but they were the first to advocate the adoption of a standard pitch for the threads of bolts, nuts, and screws.

Very little is recorded of the useful work done by these pioneers, but as an example of its value, the case may be mentioned of a punching-machine invented and worked by Maudslay about the year 1813. This was a self-acting machine with a rack feed, and it was stated then, in 1857, that no better machine for the same purpose was known. Again, when speaking of the lathe, Fairbairn said, in 1861, that for large work in engineers' shops this tool "remains nearly in its simplest form, with the addition of the slide-rest, and some improvements by Clement to equalise its action."

One of the first to introduce superior self-acting tools for metal working was Richard Roberts, who commenced business about 1815, as a maker of lathes and other tools, in Deansgate, Manchester, where he made his first iron planing-machine, now to be seen at the South Kensington Museum. About the same time he introduced the back-geared lathe head-stock, and an improved screw-cutting lathe. Following these came the slotting-machine, a wheel-cutting engine, and further improvements in connection with the lathe. His business was carried on under the



LONGITUDINAL SECTION.



TRANSVERSE SECTION.

FIG. 10.—WOLFF'S STEAM BOILER (A.D. 1804).

style of Hill, Roberts & Co., until 1824, when the firm of Sharp, Roberts & Co. came into existence at Atlas Works, Manchester.

As a practical proof of the eminent services rendered by Roberts towards the advancement of mechanical art, we may refer to the lathe illustrated in Fig. 40. This tool in question has been in continuous use at the Gorton Foundry, Manchester, ever since it was made, and is practically in its original condition. The rate of feed is varied as required by the change opposition of the small-toothed pinion working in the various circular paths on the face of the flat-toothed wheel at the tail of the headstock, which is held up to its work by a spiral spring strung on its shaft, and it is interesting to note that the toothed pinion as well as the flat-toothed wheel are the original ones, which have been at work ever since the lathe started. Two vertical bevelled wheels regulate the direction of the slide-rest movement, reversal being effected automatically by means of a horizontal rod passing through the lower part of the slide-rest. A screw-cutting lathe, made by Roberts in 1820, is also in use at the same works, but we regret that limitation of space prevents our including more than a passing reference to this machine.

In 1825, after the great strike of cotton operatives, Roberts invented the self-acting spinning mule, in the manufacture of which he first adopted the use of standard templets. His career was a remarkable one, and his series of inventions connected with self-acting tools introduced a precision, celerity, and cheapness into the production of machinery never known before. As a pioneer of machine-tools, Roberts occupied a place between the times of Maudslay and Clement on the one hand, and of Whitworth on the other; but it is to be feared that his claims to the gratitude of the engineering world are insufficiently recognised in the present day.

Having now referred briefly to some of the advances made in tools, it may be interesting to mention a few examples of progress in other directions. Fig. 7 illustrates a high-pressure, non-condensing engine, patented by Trevithick and Vivian in the year 1802. The specification also

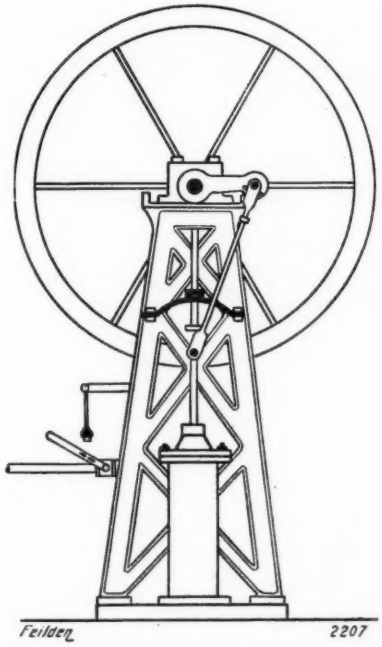


FIG. 11.—VERTICAL STEAM ENGINE.
(A. CHRISTIE AND CO., 1824.)

provides for the construction of a "vibratory" engine, in which the boiler as well as the cylinder oscillated on pivots, so that the revolution of the crank

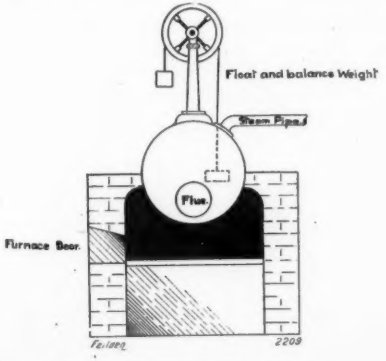


FIG. 12.—HORIZONTAL STEAM BOILER.
(A. CHRISTIE AND CO., 1824.)

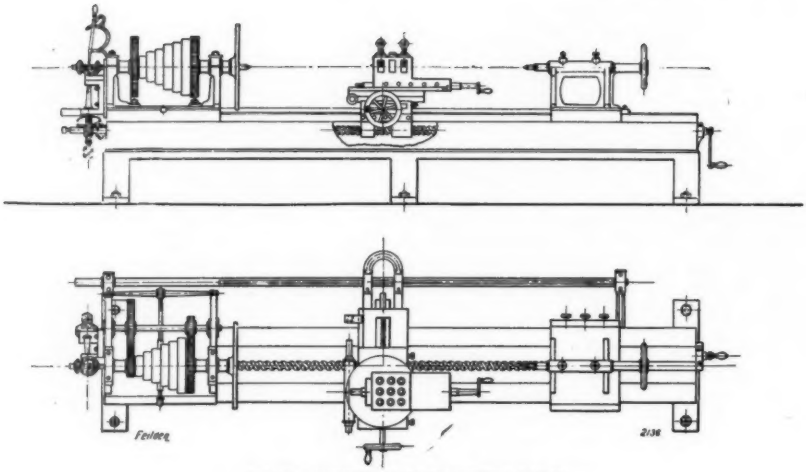


FIG. 13.—WHITWORTH SCREW-CUTTING LATHE.
(From a print published in 1851.)

might be followed without the employment of a guide-wheel and connecting-rod. The thought appears to have occurred to the inventors that it was not absolutely essential either to boil the cylinder or to shake up the boiler, for the specification suggests that the cylinder may be placed outside the boiler, and allowed to oscillate separately. This type of engine does not seem to have been very much used about the time of its invention, but in the form indicated by Fig. 8 it was afterwards applied by Penn and others in connection with paddle-wheel steamers, until superseded by the vertical type of marine engine.

In another patent Trevithick anticipated modern methods by trying to find a more direct contrivance than the beam for connecting the piston with the crank. Again, in making use of steam at pressure as high as 120 lbs. per sq. in., he was distinctly in advance of the times, and in the Cornish pumping-engine he gave the world a motor celebrated for its economy of fuel, and remarkable as the first engine at all comparable as to efficiency with modern types. The prophetic views of Trevithick as to iron shipbuilding were not accepted in his day, but they have not been without influence upon that important industry.

Having erected a steam-threshing machine upon the estate of Sir Charles Hawkins in Cornwall, he foresaw the advantages which would follow the application of steam in connection with agriculture, and endeavoured to interest the Board of Agriculture in the subject. In a communication to that body Trevithick expressed the opinion that by the adoption of steam-driven agri-

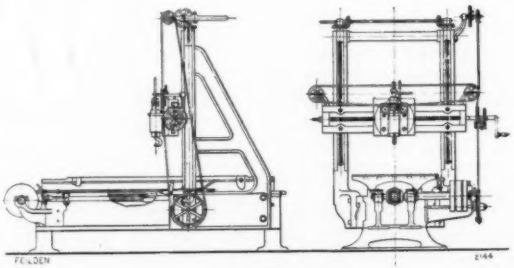


FIG. 14.—WHITWORTH PLANING-MACHINE.
(From a print published in 1851.)

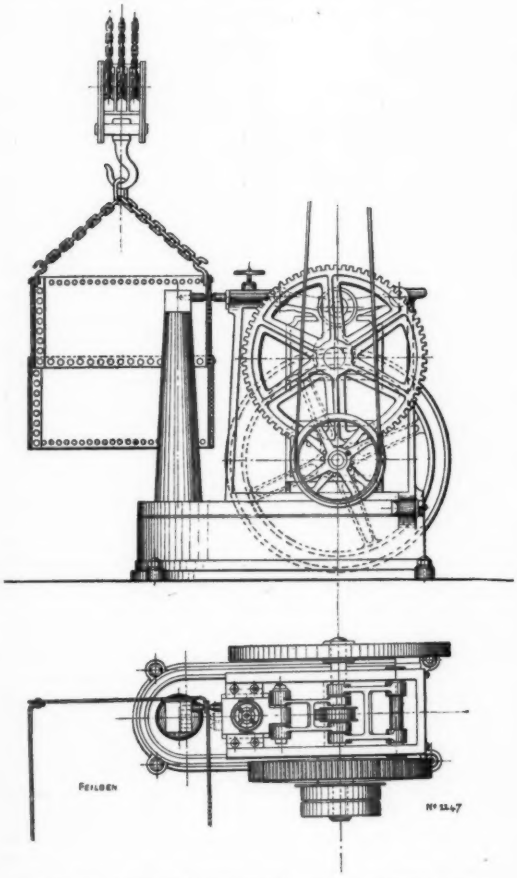


FIG. 15.—FAIRBAIRN'S MECHANICAL RIVETING MACHINE (1837).
From an engraving in the possession of the Institution of Mechanical Engineers.)

cultural machinery the population of the kingdom would be doubled and its markets would be made the cheapest in the world.

Trevithick was undoubtedly the first to undertake the construction of railway and road locomotives, and to apply them with practical, though, perhaps, not with financial success. He made an unsuccessful attempt to interest the Admiralty in the question of steam navigation, and was one of the first to undertake the erection of British engines and machinery in foreign countries. His life was for the greater part spent in the endeavour to demonstrate to an unwilling people the manner in which the foundations of Britain's industrial supremacy might be laid, and although his ideas were ultimately adopted they brought practically no reward for the gifted man to whom their inception was due.

The compound engine was revived in the year 1804 by Wolff, whose engine is diagrammatically represented in Fig. 9, and who used steam at a much higher pressure than was employed by Watt. Wolff also introduced an improved type of boiler, which, as may be seen by Fig. 10, was distinctly suggestive of the modern water-tube boiler. Judging from comparative tests made in 1815, it appears that the coal consumption in Wolff's engine was very much less than in that of Watt; but although largely adopted in Cornwall it fell into disuse after a time.

In the year 1807 Maudslay patented a "portable engine," embodying some ingenious improvements on the valves and other working parts. The engine in question is thus spoken of in 1830 by Mr. E. Galloway: "There are few machines which display more ingenuity, either on account of skilful arrangement or neatness, than this; and as regards its utility it need only be said that long continued trials have fully established the great excellence of Mr. Maudslay's engine."

An engine designed in 1824 by Alexander Christie & Co., of Sheffield, is worthy of notice as an effective and compact high-pressure engine of a type which has survived until recent times. The drawings reproduced in Figs. 11 and 12

refer to an engine and boiler erected in Burdekin's anvil works, Sheffield.

Looking across the Atlantic, we find that about the year 1807 Evans had proved successful in his efforts to introduce steam navigation, and that a considerable number of his engines were used for driving saw-mills, flour-mills, paper-mills, ironworks, and cloth manufactories. Robert Fulton, another well-known American engineer, had also succeeded in constructing a steamboat, which was launched at New York on October 3rd, 1807, and began to ply between that city and Albany, a distance of 144 miles. In 1812 the steamboat *Comet* was launched on the Clyde, and numerous other attempts were made in Great Britain. Although of very imperfect construction, these early steamboats so far proved the advantages of steam navigation, as to encourage other persons to construct more suitable vessels, and to equip them with engines made specially for the work to be performed.

During the period with which we are now dealing, Fairbairn had not commenced to exercise his influence upon the progress of mechanical science, for in March, 1804, he had just been apprenticed to a millwright at Percy Mains Colliery, in Northumberland, where he made the acquaintance of an engine-driver named George Stephenson, of whom the world was destined to learn much in succeeding years. In partnership with an old shopmate named Lillie, Fairbairn started business in an old shed situated in High Street, Manchester. This was in the year 1817, and until then the carpenter and millwright were, to a great extent, the sole representatives of mechanical art. Consequently, wood was largely used in mill-work; shafts were generally square, and the prevailing impression appeared to be that the more drums and wheels one could contrive to squeeze in, the better would be the mill. Fly-wheels and gear-wheels were secured to the shafts by the use of wooden wedges, into which thin wedges of iron were driven. When Fairbairn started work in Manchester, the mills were driven by large cast-iron shafts, on which huge wooden drums of 4 ft. or 5 ft. diameter moved at the leisurely rate of about forty revolutions per minute. Couplings were universally bad, and Fairbairn says the "sound of their complaining could be heard at some distance from the mill." Moreover, they were always breaking down, so that Sunday became a day when the millwright might confidently expect to find full occupation in making good the defects developed during the past week. In 1818, Fairbairn obtained his first important contract to furnish the mill-gearing for a new factory then being built in Manchester The shafting used by Fairbairn was all turned, the wheels were bored, and couplings of the half-lap type were adopted. Higher speeds were used, the sizes of shafts and pulleys were reduced, and the whole system of belts was supplied. As he then had no engine, the whole of the shafting was turned up in a foot-lathe, and the work was completed in so satisfactory a manner as to secure a great reputation for the new firm, whose improvements constituted a veritable revolution of the whole system of power transmission.

The United States is a country now so justly celebrated for the excellence of machine-tools and kindred appliances that it is curious to recall the very backward state of things which prevailed earlier in the century. John Fritz, the veteran metallurgist, describes how the first boiler-plate was rolled at the Coatesville rolling-mill. The blooms were heated on a grate fire, and the rolls were driven by an old-time water-wheel. Sometimes it would be necessary for all the workmen to run and get on the buckets and tread with them, in order to prevent a stall, which would have caused fire cracks in the rolls, and, sooner or later, a broken roll. Rolling-mills were made with leading spindles, in which a groove was cut to weaken them, so that if any extra strain should come on the rolls, the spindles would break instead of the roll; and the couplings were made light so as to act as a kind of safety valve. In addition, there was a breaking-box between the screw and the roll. If one or other of these devices did not break each day the pattern was made lighter.

Consequently, breakages occurred several times daily, causing constant annoyance and loss of time.

The first large engine for the city waterworks of Philadelphia was built by the aid of the most primitive tools. The bar used for boring out the cylinder was operated by means of levers, so that men walking around the cylinder could propel the cutting tools, and gradually force the cutters through the cylinder. After that the inner surface had to be filed to a sufficient degree of smoothness. It is stated that the whole operation occupied about one month. Early machine-tools were of the crudest description in the city of Philadelphia, and probably in other American cities. Most of the lathes were partly made of wood, and very few signs of improvement were discernible until machine-tools were imported from England. The first planing-machine was introduced into America about the year 1830, and Dr. Sellers remembers a planer, having the table dragged backwards and forwards by a chain, being put into use at his father's shops when he undertook to build a locomotive in the year 1834.

During the period comprised within the years 1830—1857 the inauguration of the railway system gave an immense impetus to commerce generally, and to mechanical engineering in particular. Special machinery was constantly required for the equipment and maintenance of railroad systems, as well as for such industries as shipbuilding, bridge, and structural work. We therefore see that the design and construction of machine-tools had a most important bearing upon the advances made during the epoch which we now have to consider, and the development of that industry alone indicates in a striking manner the progress of mechanical engineering.

In England, the work commenced by Roberts and others was taken up by Whitworth, who started in business during the year 1833, and made his name famous by working out and introducing the system of gauges and screw threads suggested at an earlier date by Maudslay and Clement. He was the first mechanician to realise the importance of minute accuracy of

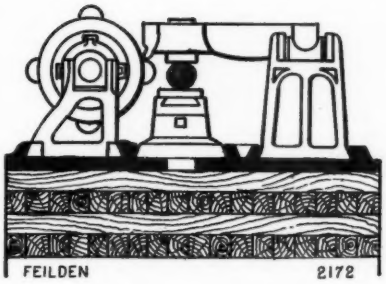


FIG. 16.—NOSE-HELVE HAMMER.

workmanship, and for the purpose of rendering this possible, he devised and produced machinery for measuring by contact instead of by sight. It was Sir Joseph Whitworth who introduced surface-plates to make possible the production of other plane surfaces by means of the scraper; and the complete series

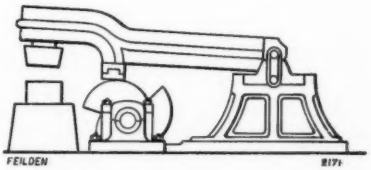


FIG. 17.—BELLY-HELVE HAMMER.

of machine-tools, of which he commenced the construction in 1835, marked a distinct epoch in the history of mechanical work throughout the civilised world. We reproduce drawings of two familiar tools of Whitworth's make. The lathe shown in Fig. 13 is adapted for parallel, spherical and face turning, barrelling, screw-cutting, and boring, by suitable adjustment of the

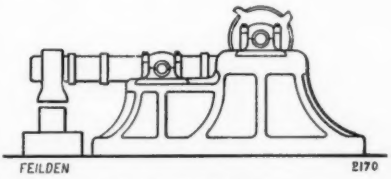


FIG. 18.—TILT HAMMER.

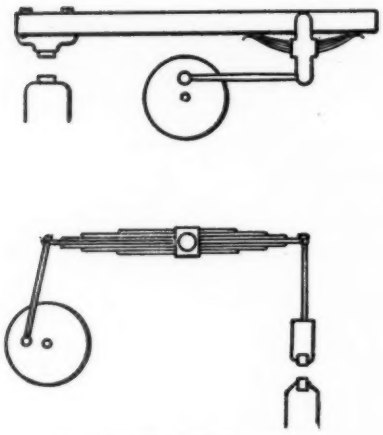


FIG. 19.—DIAGRAMS OF POWER HAMMERS.

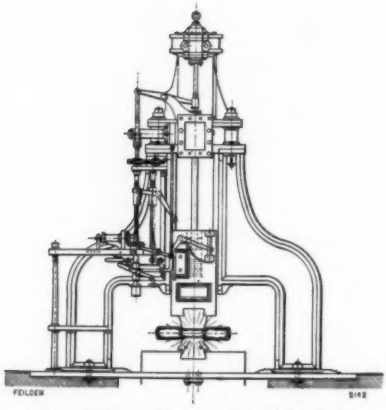


FIG. 22.—NASMYTH'S IMPROVED STEAM HAMMER.
(From a print published in 1851.)

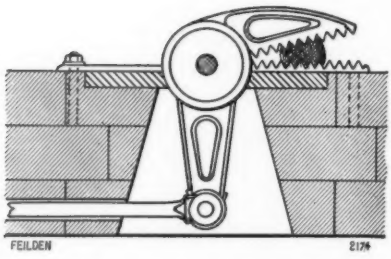


FIG. 20.—CROCODILE SQUEEZER.

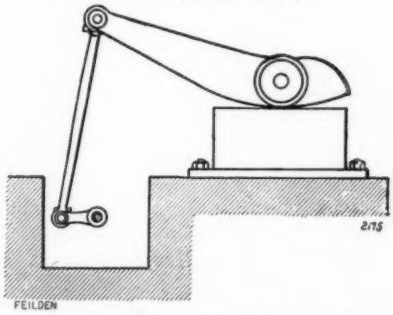


FIG. 23.—DOUBLE-ACTING SHEARING MACHINE.

gear wheels. The holder for the work is that known as "Clement's equilibrium" chuck, in which two arms at the circumference catch and drive round some projecting part of the work, resting upon the central pin. This lathe lacks some of the refinements present in modern high-class tools, but it does not differ essentially from thousands of lathes still used in the present day. Fig. 14 is from a drawing of Whitworth's self-acting planing-machine, the first tool of its kind which made it possible to rely entirely upon the absolute accuracy of machined work. Although differing in several details from planing-machines of the present time, the general principle is practically the same. It will be noticed in the front elevation that the tool is reversible, so that a cut may be made during the motion of the table in each direction. As our readers are aware, the reversing tool socket, known amongst workmen as a "Jim-Crow," has been abandoned owing to the difficulty of ensuring accuracy of position. We believe the last "Jim-Crow" used in London was at the works of Bryan, Donkin & Co., where it was given up finally because the men who could work it successfully had left or died, and the newer hands could not make it answer satisfactorily.

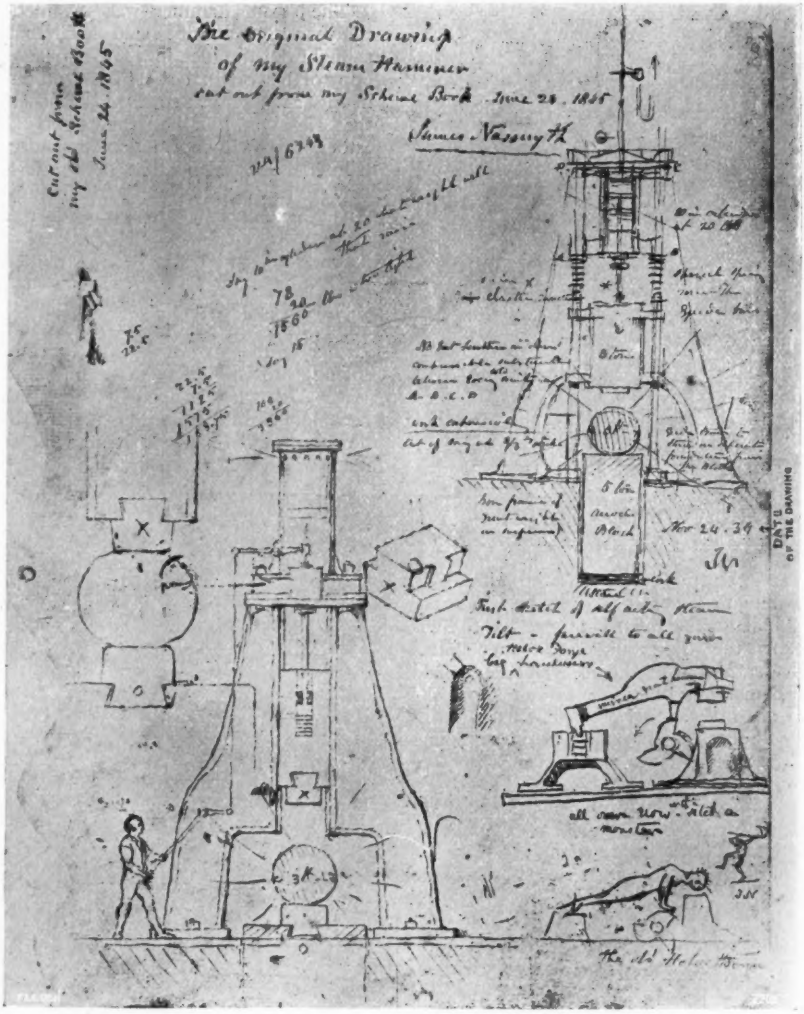

The Original Drawing
of my Steam Hammer
cut out from my Sketch Book June 24. 1845
James Nasmyth
Cut out from my old Sketch Book June 24. 1845
DATE OF THE DRAWING

FIG. 21.—NASMYTH'S ORIGINAL DRAWING OF THE STEAM HAMMER.
(From a facsimile in the possession of the Institution of Mechanical Engineers.)

It is worthy of note that the making of automatic tools was distinctly stimulated by every strike on the part of workmen, and concurrently with every advance in the design of such tools there was an advance in the quality of the work executed, and a diminution in its cost. Thus we find that whereas the cost of chipping and filing a square foot of metal in 1826 was fully 12*s.*, the same work

FIG. 24.
THE CREUSOT STEAM HAMMER (100 METRIC TONS).
(From a photograph furnished by Schneider & Cie.)

could be performed by the aid of a planing-machine in 1856 for *1d.* A strike of boiler-makers in 1837 suggested to Fairbairn the desirability of a mechanical riveter, and with the first machine made two men and a boy put in as many rivets in one hour as had previously been put in by three men and a boy in twelve hours. Figs. 15, illustrating Fairbairn's riveter, are reproduced from engravings in the possession of the Institution of Mechanical Engineers.

Until the year 1837 no very urgent necessity appears to have arisen for the adoption of more powerful or more tractable forging appliances than the old-fashioned helve and tilt hammers. The "nose-helve" hammer is shown in Fig. 16, the "belly-helve" hammer in Fig. 17, and the tilt hammer in Fig. 18. Lighter forms of power hammers are diagrammatically illustrated in Fig. 19. In these springs are introduced with the idea of imparting elasticity to the blows struck. For the treatment of puddle-balls, the crocodile squeezer (Fig. 20) was introduced as an improvement on the hammer, and other forms of squeezers were also adopted of still better construction.

The steam hammer was invented in the year 1839, and it is said that Nasmyth thought out the idea in a few minutes. A copy of his original sketch is reproduced in Fig. 21. From this it will be observed that Nasmyth inherited the talent of his father, the well known Scotch landscape painter, and also that he possessed that gift of humour which some prejudiced Anglo-Saxons affect to think does not exist north of the Tweed. Before the steam-hammer appeared in an easily-worked and marketable form an immense amount of trouble was necessary. After numerous attempts, Nasmyth thought of abandoning further effort, but Robert Wilson at last solved the problem of efficient control. With Wilson's motion, every variation became possible, from the heaviest blow down to a tap so light that an egg placed in a wine-glass on the anvil might be

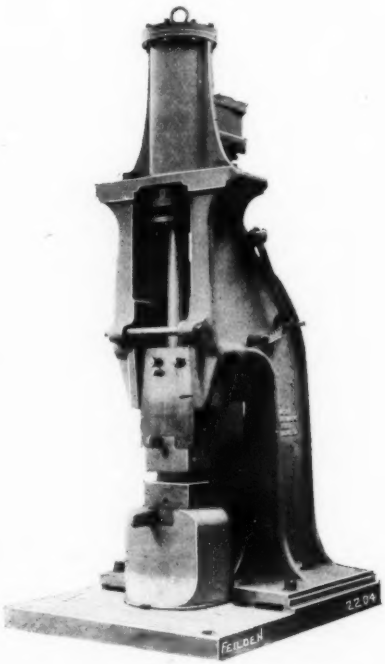


FIG. 25.—SMALL STEAM HAMMER FOR SMITHWORK.
(B. AND S. MASSEY, 1900.)

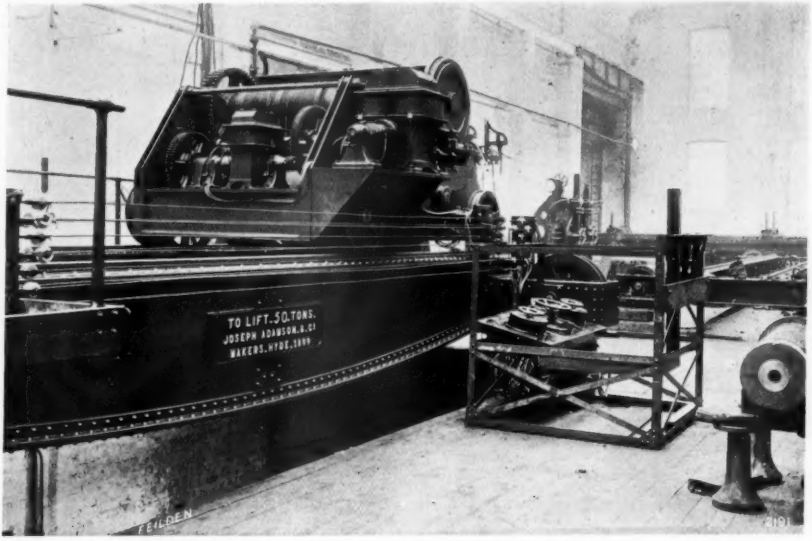


FIG. 26.—ELECTRIC TRAVELLING CRANE, TO LIFT 50 TONS. BUILT BY JOSEPH ADAMSON AND CO., HYDE, FOR THE OPENSHAW WORKS OF ARMSTRONG, WHITWORTH AND CO.

This crane is constructed in accordance with the most advanced practice, and has four separate motors—one for each motion. The load is carried by steel-wire ropes, the main and auxiliary lifting motions being fitted with automatic brakes. All the switches are in the attendant's cage, which will hang below the girder.

struck without breaking the shell. In 1843 the first hammer was sold to the Low Moor Ironworks, and orders shortly afterwards followed from all parts of the country. Fig. 22 shows the steam hammer as made in the year 1851 by Nasmyth. Wilson's later improvements made practicable the construction of hammers of sizes which could not possibly have been worked by valves of the ordinary description.

Amongst the valuable series of inventions patented by Nasmyth may be mentioned machinery for boring, shearing, stamping, and planing metals, and improvements in connection with railway carriages, pile-driving, atmospheric railways, stationary engines,

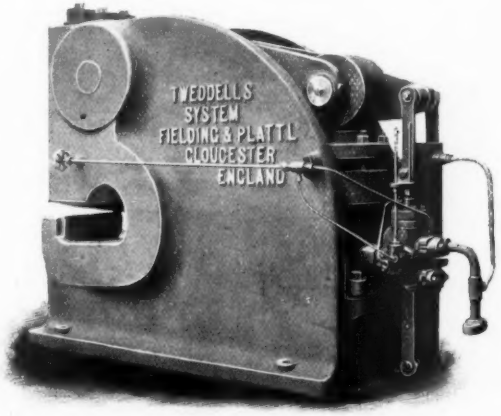


FIG. 27.—NEW LEVER-TYPE HYDRAULIC SHEARING MACHINE, AS BUILT BY FIELDING AND PLATT, LTD., FOR THE GREAT WESTERN RAILWAY WORKS, SWINDON.

It is automatic in action, with complete and instantaneous control of speed, so that it may be worked continuously or by single strokes. The stroke may be instantly adjusted to the thickness of the plate from the front of the machine.

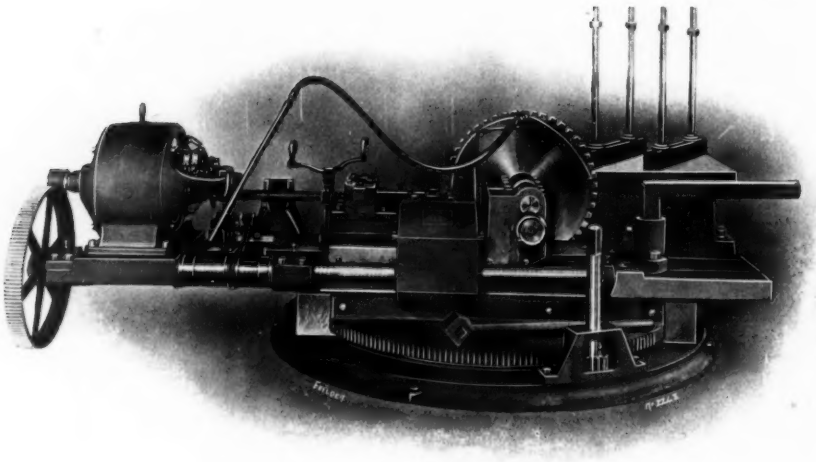


FIG. 28.—BRYANT METAL SAWING MACHINE WITH CIRCULAR BASE AND ELECTRIC MOTOR. MADE BY THE Q. AND C. CO., CHICAGO.

Rails, structural steel castings, and metal bars of any kind can be cross-cut, by the aid of this machine, at any angle to which the base may be set, saving labour and economising workshop space.

power transmission, the application of heat, stone-working, brick and tile manufacture, calico printing, and drying cylinders.

About the time of which we are now writing, Richard Roberts gave several other inventions to the world, dealing with telegraph apparatus, hydraulic machinery, pumps, hoists, and metal-working machines. His "multifarious" punching - machine, patented in 1847, is particularly worthy of notice. This machine, by whose aid iron plates could be punched according to any desired pattern, was designed at the

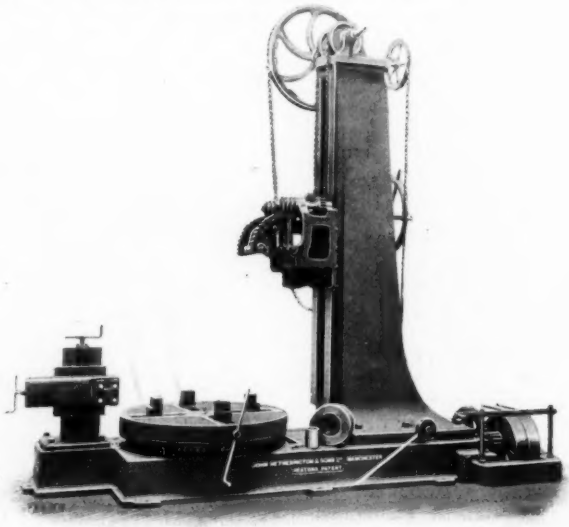


FIG. 31.—HEATON'S PATENT FLANGING MACHINE. BUILT BY JOHN HETHERINGTON AND SONS, LTD., MANCHESTER, FOR FLANGING BOILER FLUES FROM 2 FT. TO 4 FT. DIAMETER, AND FROM 1 FT. 6 INS. TO 4 FT. LONG.

The bed is furnished with a revolving universal chuck, as shown above, and the movable pillar carries a rising and falling head, in which the flanging rods are operated. The head can readily be adjusted for different lengths by means of the hand-wheel, partly seen in the illustration.

special request of the contractors for the Conway Tubular Bridge, and it is said that without such an appliance the bridge would not have been completed by the specified time.

In the year 1841, Fairbairn commenced the introduction of a series of patents relating to steam engines, iron ship-building, and the Lancashire boiler. The last patent was taken out in conjunction with John Hetherington, a well-known engineer and tool-maker.

Fairbairn also patented an improved type of crane, a riveted tubular girder construction of beautiful design.

The final revival of the compound engine took place in 1845, when McNaught improved the beam-engine by adding a

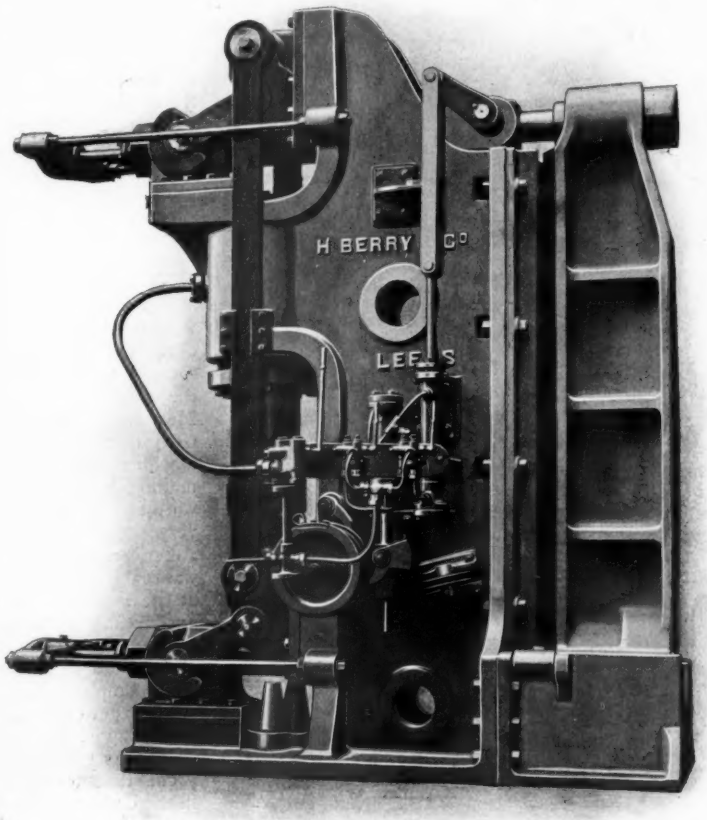


FIG. 29.—HYDRAULIC PLATE-BENDING MACHINE FOR BOILER WORK. BUILT BY H. BERRY AND CO., LTD., LEEDS.

The plates are fed through vertical dies operated through a toggle-gear by a single hydraulic cylinder, thus securing uniform curvature up to the extreme edge. Power may be increased in proportion to the curvature required, and cover-plates for butt-joints may be bent to the correct sweep in the same machine.

high-pressure cylinder. About that time a large number of simple engines were altered or "McNaughted," as the operation was termed, and the compound engine, the greatest improvement since the time of Watt, at last became an accomplished fact.

In the year 1846, Armstrong patented a hydraulic crane, and in succeeding years took a leading part in the practical realisation of the ideas formulated at the very commencement of the century by Joseph Bramah.

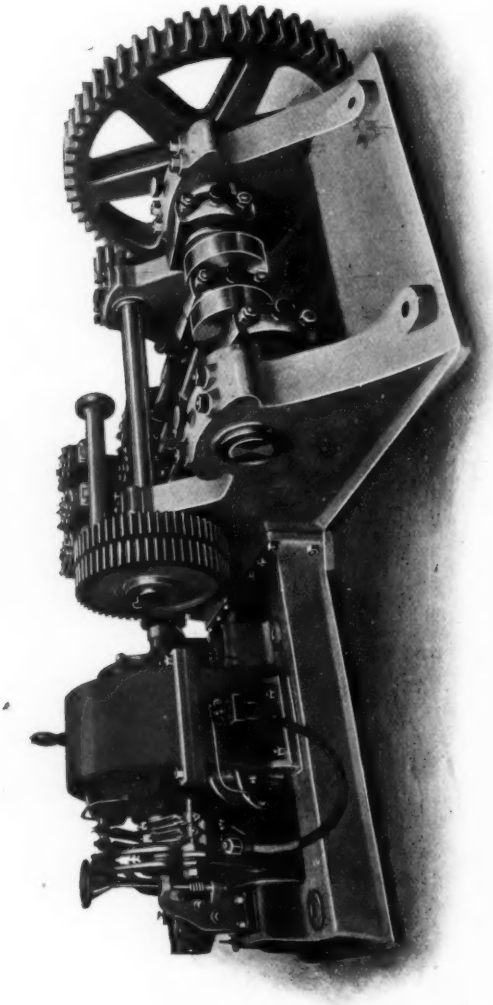


FIG. 30.—ELECTRICALLY-DRIVEN HYDRAULIC PUMPS. H. BERRY AND CO., LTD., MAKERS, LEEDS.
The illustration shows a set of three-throw horizontal pumps, to which is attached a four-pole motor of 50 B.H.P. These pumps are suitable for pumping into accumulators or directly into machines, and can be made to work at any desired pressure.

The demand for iron plates of large dimensions and of increased thickness, for boiler-making and constructional work, necessitated the application of more powerful machinery in ironworks and rolling-mills. Amongst other primitive tools, the shears of the kind illustrated in Fig. 23 were found to be no longer suitable under the altered conditions of work. To meet the new demands, and especially those in connection with the Conway Bridge, Messrs. Thorneycroft & Co. produced a shearing machine capable of making a cut of 10 ft. wide at one stroke. A very similar machine of American manufacture was exhibited in 1855 at the Paris Exhibition, and although this appliance was considered at the time to be somewhat complex and more liable to get out of order than English-made machines, its production is proof that tool-making in the United States had already commenced in earnest.

Wednesday, January 27, 1847, will always remain a memorable day in the annals of

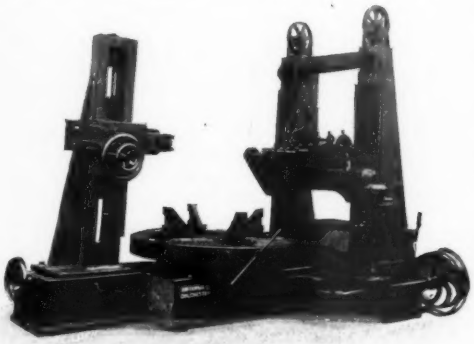


FIG. 32.—THREE-SPINDLE BOILER FLUE DRILLING MACHINE. MADE BY THE BRITANNIA CO., COLCHESTER, FOR FLUES UP TO 5 FT. 6 IN. DIAMETER, AND 5 FT. 6 IN. LONG.

The two outer spindles of this machine have a swivelling adjustment, so that they may be truly radial for any diameter of flue. The centre spindle points to the centre line. Each drill spindle has self-acting feed and quick return motions, and the drills can be worked independently or simultaneously. Mechanism is provided for the chuck by which the circle may be divided to give any required number of holes.

mechanical science, for it was then that the Institution of Mechanical Engineers came into existence. If no other evidence were available, the names of those gentlemen who took a leading part in the foundation of the Institution would be sufficient to indicate the wonderful progress which had been made, even at that comparatively early date. It is unnecessary to refer at length to the illustrious career of George Stephenson, the first President, of whom Scott Russell wrote in 1848: "In our late President England has lost one of her most distinguished men, the world one of its greatest benefactors." Succeeding his father, Robert Stephenson occupied the presidential chair for a period of four years, and those who seek for records of his work will still find them in the Newcastle High-level Bridge, and the Britannia and Conway Tubular Bridges, as well as in other examples of constructional engineering. Sir William Fairbairn was the next President of the In-

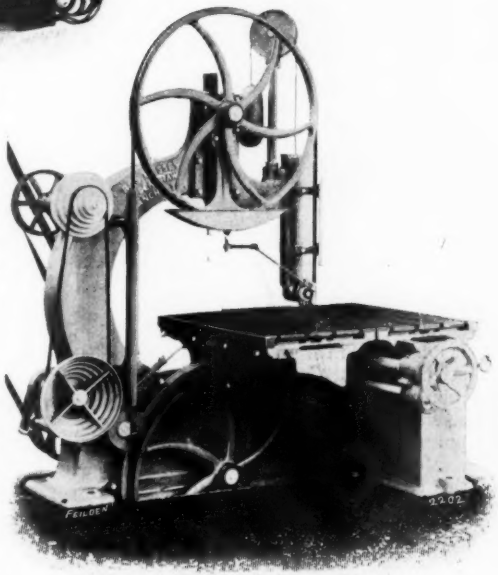


FIG. 33.—BAND-SAW FOR COLD METALS. MADE BY B. AND S. MASSEY, OPENSHAW.

Although chiefly intended for straight cuts up to about 18 ins. deep, this machine will make curved cuts if the metal is not too thick. The table is self-acting, and made in two parts, capable of working separately or together. Twelve different feeds are provided for the table.

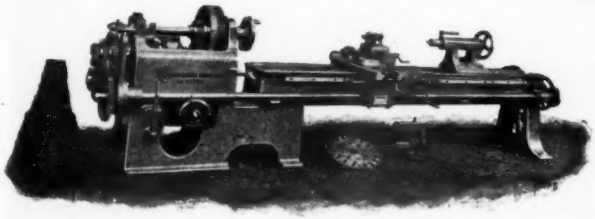


FIG. 34.—10-IN. CENTRE, SELF-ACTING, SLIDING SURFACING, SCREW-CUTTING LATHE, ARRANGED TO SLIDE TAPER AND FURNISHED WITH SELF-CONTAINED MOTOR. SIX CHANGES OF SPEED ARE GIVEN BY THE CONTROL SWITCH, AND SIX BY THE PURCHASE GEARING. THE SPEED OF THE SPINDLE THEREFORE RANGES FROM 7 TO 178 REVS. PER MINUTE. GREENWOOD AND BATLEY, LTD., MAKERS, LEEDS.

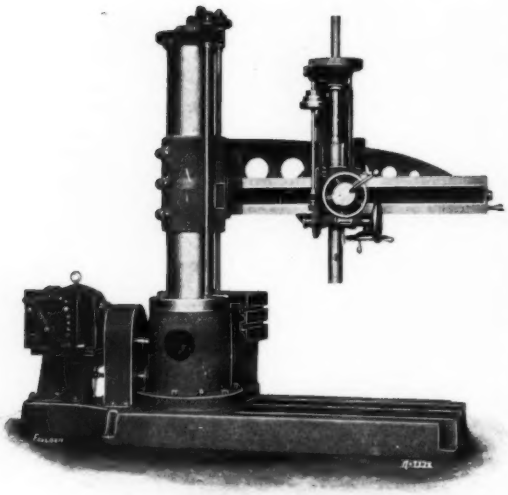


FIG. 35.—RADIAL DRILL WITH STRAIGHT BASE ROUND COLUMN, AND ELECTRIC MOTOR ON BASE. MADE BY THE BICKFORD DRILL AND TOOL CO., CINCINNATI.

stitution, and we have already referred to his labours in the cause of mechanical science. But he also deserves to be remembered as the author of numerous scientific works, many of which remain of practical value to the present day.

Men who are old enough to remember the condition of mechanical engineering in the year 1830, and to compare it with the state of development attained in 1856, know how remarkable were the improvements introduced, and are able to appreciate how greatly the world is indebted to the men whose names have been mentioned. Those who belong essentially to the present age may, perhaps, affect little enthusiasm with regard to the practice of 50 years ago. Various achievements with which we are now familiar were then unknown, and engineers of that day were not expected to perform tasks such as are now frequently necessary. Nevertheless, it is perfectly evident from existing drawings and practical examples, that so far as accuracy of design and soundness of execution are concerned, the work of our predecessors is by no means unworthy of comparison with that of more recent times.

With the year 1857 came the dawn of a new era, in which steel, hitherto regarded more or less in the light of a luxury, was destined to usurp the place of wrought-iron in almost every department of mechanical work. It was in the course of a paper read in 1856 at the Cheltenham Meeting of the British Association, that Henry Bessemer first announced to the world the discovery of

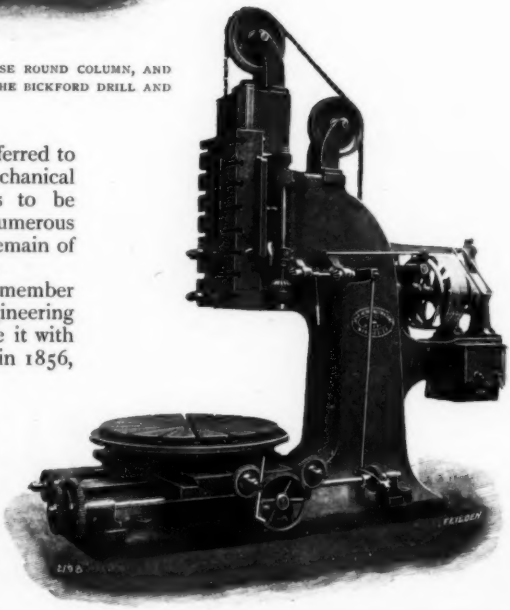


FIG. 36.—SCREW-DRIVEN SLOTTING MACHINE, WITH MOTOR-DRIVEN OVERHEAD COUNTERSHAFT. JOHN HETHERINGTON AND SONS, LTD., MAKERS, MANCHESTER.

The compound slide and circular motions for the table of this machine are self-acting in the longitudinal, transverse, and circular feeds, any of which may be varied whilst the machine is at work. The table can be locked in any position, and the worm may be disengaged to permit the table to be turned by hand for setting work.

his process. This great invention was not carried into practice without considerable difficulty, but Bessemer unremittingly applied himself to perfect the process, and his efforts were ably seconded by those of many prominent members of the Institution of Mechanical Engineers. William Menelaus and John Ramsbottom were amongst the first makers of Bessemer steel upon an extensive scale; Daniel Adamson and the Galloways of Manchester applied the new material to the construction of steam boilers; Benjamin Walker, of Leeds, undertook the manufacture of converting and rolling plant; and other engineers soon began to use steel in the construction of engines and various kinds of machinery.

About the year 1861, the horizontal steam engine began to be recognised as a more useful and convenient type than the beam engine.

Besides those already mentioned, a number of other engineers were concerned in the development of the steam engine. John Elder much improved the compound engine, especially in connection with steam navigation. Bourne's marine engine, with "return connecting-rod," was much used at one time, as also was the "trunk" engine of Penn, and the old-type vertical marine engine of Maudslay. Simple and compound "inclined-frame" engines, as designed by Brunel and others, were much used. Finally, however, the steam engine began to assume the forms with which we are familiar in the present day.

In 1864 the Bessemer process was introduced in the United States, but, as John Fritz says, "the difficulties first encountered in that country were enough to appal the bravest hearts." America is largely indebted to Fritz, Alexander Holley, William Jones, and other metallurgists for the introduction and improvement of the Bessemer process.

It would be difficult to decide which was the more important of the two great metallurgical inventions, the Bessemer or the Siemens process of making steel. There can be no doubt, however, as to the wonderful results which have followed the introduction and development of the latter process. The superiority of Siemens and Siemens-Martin steel for structural work, shipbuilding, boiler-making, and machine making, has undoubtedly exercised a most important influence in aid of the marvellous progress made within the latter part of the past century.

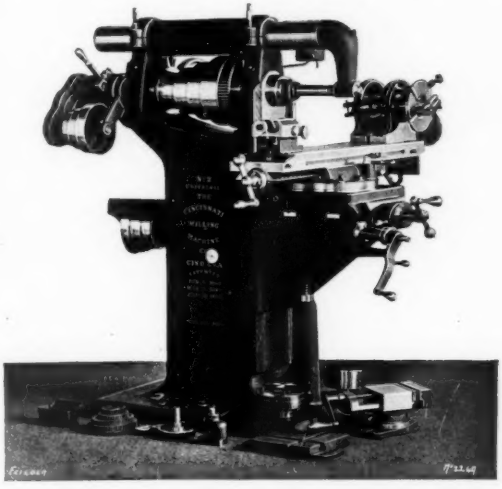


FIG. 37.—"UNIVERSAL" MILLING MACHINE. MADE BY THE CINCINNATI MILLING MACHINE CO., U.S.A.

The operating handles of this miller are in clutch form, and may be disengaged, whilst remaining in position. They are all in front of the machine, and situated so that adjustments may be quickly and easily made. Sixteen changes of spindle feed and twelve changes of feed speed for each of the spindle speeds are available. The circular swivelling carriage admits of convenient clamping, and the indexing and dividing head can be secured at any angle.

Under the new conditions of steel manufacture, far larger, heavier, and more rapidly working machinery became necessary. John Fritz long ago introduced the three-high rolling mill at the Cambria Works; and in succeeding years various

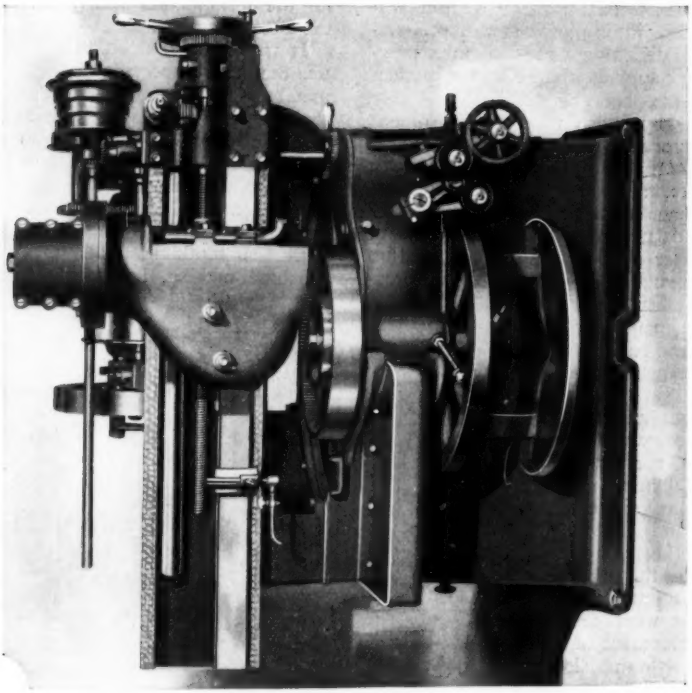


FIG. 38.—FELLOWS GEAR-SHAPER. (THE FELLOWS GEAR-SHAPER CO., VERMONT, U.S.A.)

The medal of the Franklin Institute was recently awarded for this ingenious machine, the essential principle of which is a gear-shaped planing cutter. In action the cutter is fed radially into the blank to the proper depth. Then the cutter and the blank are slowly rotated in unison, whilst the cutter continues its planing motion. The combined effect of the rotary and reciprocating motions is that teeth are formed in the blanks which exactly correspond in shape with the cutter teeth and with each other. In the illustration the machine is in the act of cutting an internal gear.

devices were added, such as lifting and feed tables, "pushers," and, in fact, every possible appliance for the purpose of reducing hand labour to a minimum. In our own country, John Ramsbottom effected great improvements in the engines and gearing of rolling mills.

Further modifications of the steam hammer were made with the view of adapting this valuable tool to steelmaking and other engineering requirements. Steam was applied above the piston to increase the force of the blow, and in some cases the cylinder was made movable so that its weight might furnish additional power. Ramsbottom's admirable piston-rings contributed in no small degree to the practical success of the modern steam hammer, as well as of locomotive and other engines. Ramsbottom also introduced the duplex horizontal steam hammer, in which no anvil was required, the impact of each "tup" being neutralised by that of the other. Steam hammers gradually increased in size and power, the 40-ton hammer erected by Nasmyth at Woolwich being eclipsed by one of 80 metric tons, built about 1878 by Schneider & Cie., of Creusot, which was subsequently modified so that the weight could be increased to 100 metric tons. Fig. 24 is reproduced from a photograph of this

remarkably fine tool, which was the largest in the world until the installation of the 125-ton hammer at the Bethlehem Steel Works in the year 1891. A small steam hammer of the latest and most improved type is seen in Fig. 25. This tool is made for smith-work by B. & S. Massey, of Openshaw. As may be noticed, the base-plate is bored to receive the turned anvil-block, thus preventing any lateral movement. The valve-gear is of the combined self-acting and hand-worked type, by the aid of which blows may be struck at any speed and of any duration. The power can be varied as desired, and dead blows can be given at any moment without interrupting the continuity of operation.

With the growing requirements of shipbuilders, armour-plate makers, and gunmakers, and those due to the ever-increasing power of modern engines and machinery, tasks of progressive magnitude have been imposed upon the steel-maker. Recognising the impossibility of producing an equal and uniform effect throughout a thick mass of metal by means of a sudden and violent blow, it occurred to Whitworth that the hydraulic press might advantageously be applied in forging operations. By the substitution of steady pressure for the force of impact, the "flow" of metal is caused to take place throughout the mass, thus securing equal density and strength.

The thunderous and awe-inspiring blows of the steam hammer have now given place to the silent yet inexorable power of the hydraulic press. Machines of the latter kind are applied for cogging and drawing-down ingots and for forging bars, cranks, screw shafting, and similar objects. Probably the most powerful appliance of the kind is one with a maximum power of 14,300 tons, built by the Bethlehem Steel Company in 1893 for forging armour-plate This magnificent machine is supplied with water at a pressure of 7,000 lbs. per square inch by a triple-expansion pumping engine of 15,000 h.p., and is served by two 200-ton cranes with hydraulic lift and pneumatic travel. Machines of this type though perhaps not of such tremendous proportions, are to be found in all our great steel-works, and there are others in which massive plates may be bent to any desired shape without apparent effort. Huge lathes abound in which steel ingots are cut into blocks of lengths suitable for the forgings required for guns, engine-shafts and the like. In the preparation of ingot blocks for hollow forging, horizontal boring mills are used, taking work up to 60 ins. or more in diameter, and boring holes of 20 ins. diameter with practically perfect accuracy. Hydraulic presses for fluid

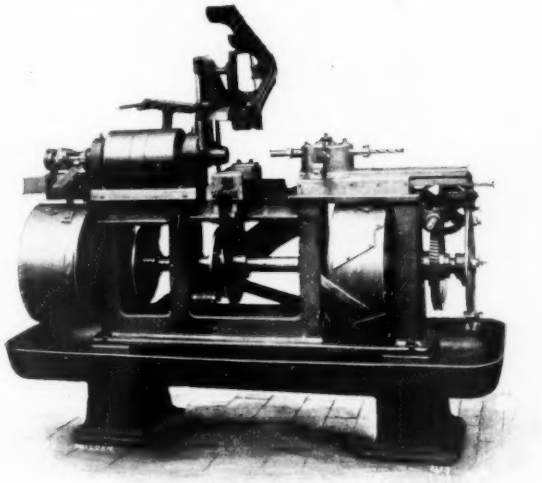


FIG. 39.—AUTOMATIC SCREW MACHINE WITH MAGAZINE.
PRATT AND WHITNEY CO., MAKERS, HARTFORD, U.S.

Small parts of machines may be finished by this tool with great rapidity and at a minimum cost. For instance, rough castings can be transformed into finished hand-wheels, with rims turned inside and outside; bosses grooved, turned, and faced on the rim; hubs faced both ends, and bored and reamed ready for their shafts. All these operations are performed automatically; no attention is necessary beyond periodical filling of the magazine, and ordinary care of the cutting tools; and one man and a boy can attend to twelve machines.

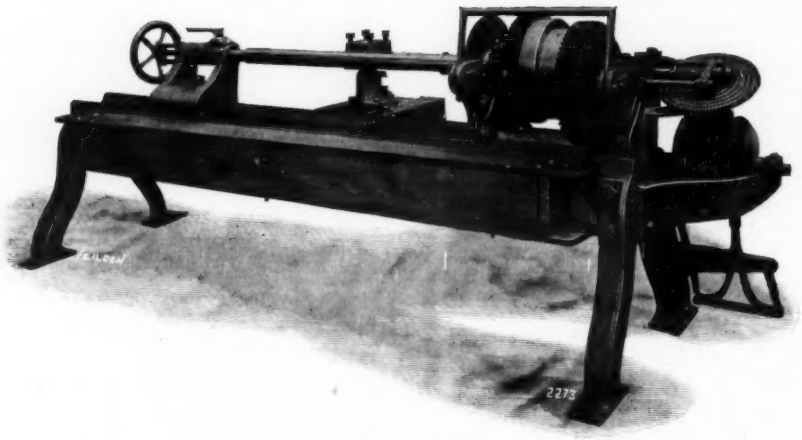


FIG. 40.—A REMARKABLE LATHE BY RICHARD ROBERTS.

The lathe represented above was made by Richard Roberts for the firm of Beyer, Peacock & Co., 83 years ago, and is still in daily use. The slide-rest bears the stamped inscription, "Richard Roberts, 1817."

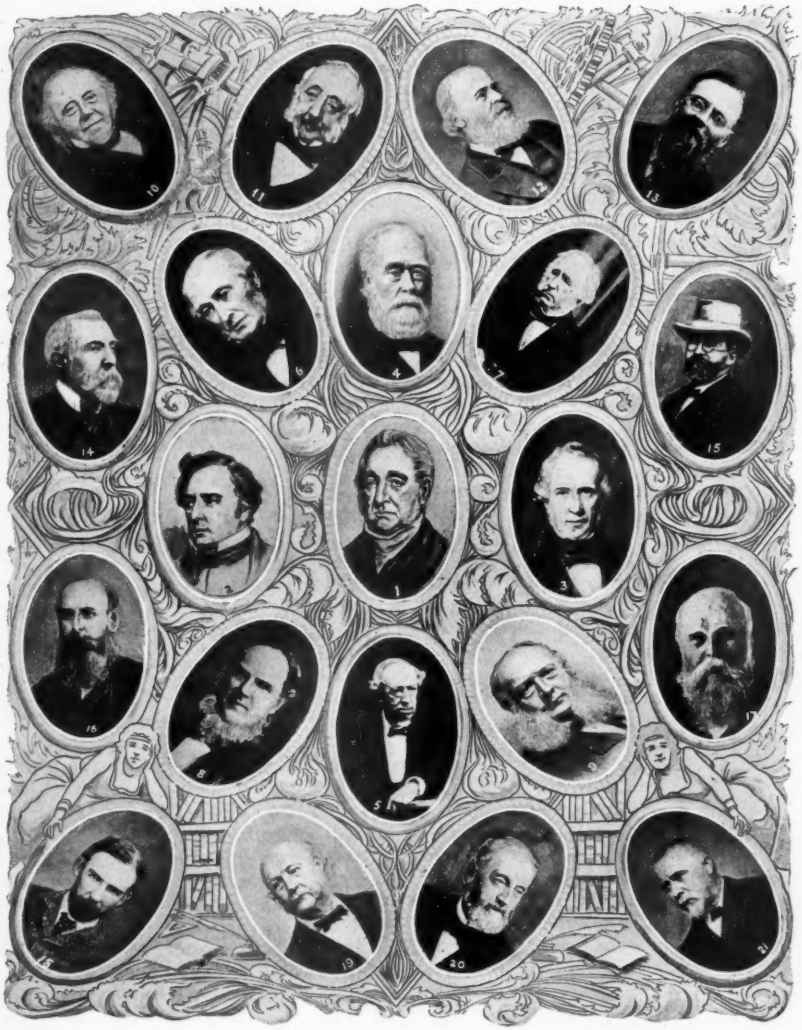
(From a photograph taken expressly for FEILDEN'S MAGAZINE by Messrs. Beyer, Peacock & Co., Ltd., Manchester.)

compression and for hollow forging, enormous machines for drilling, milling, planing, sawing, and turning, as well as smaller tools of various kinds, form part of the equipment of a modern steel-works, where also labour-saving appliances are introduced to such an extent that very little remains to be done by man. For the practical adaptation of hydraulic power to the purposes mentioned the world is largely indebted to the originative genius of Whitworth and Armstrong, as well as to the executive ability of Tweddell and others who have been concerned in the design and manufacture of hydraulic appliances.

In the evolution of modern engineering practice the Institution of Mechanical Engineers has played a leading part, and in the lives of its successive Presidents, some of whom have already been mentioned, one may trace the history of those peaceful victories which have contributed so largely to the prosperity of the British Empire, and to the welfare of the world at large.

Edward A. Cowper took up the Siemens regenerative system at an early period, and did much for the improvement of blast furnace practice. Sir Lowthian Bell is known to all the world as an indefatigable worker in practical metallurgy and in the fields of experimental research. Jeremiah Head, after devoting attention to several branches of mechanical engineering, finally became associated with the iron and steel industries of Middlesbrough. Charles Cochrane was one of the first to appreciate the advantages of regenerative stoves in heating the air for blast furnaces, and his labours, extending over many years, have been of the utmost value to blast-furnace metallurgists. But other Presidents of the Institution have also done much to develop the steel industry, partly by the magnitude of their operations, and partly by the invention and manufacture of appliances by the aid of which steel-makers were enabled to cope with the more arduous tasks placed before them year by year. John Penn was a pioneer in the evolution of marine engines; Lord Armstrong was the inventor of the hydraulic accumulator, rendering practicable the application of the principle conceived in 1802 by Bramah; but he is better known as the founder of the Elswick Works, which constitute a

PAST-PRESIDENTS OF THE INSTITUTION OF MECHANICAL ENGINEERS.*



1. George Stephenson.
2. Robert Stephenson, F.R.S.
3. Sir William Fairbairn, Bart., LL.D., F.R.S.
4. Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S.
5. John Penn, F.R.S.
6. The Right Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S.
7. Robert Napier.
8. John Ramsbottom.
9. Sir William Siemens, D.C.L., LL.D., F.R.S.
10. Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S.
11. Thomas Hawksley, F.R.S.
12. Sir Lowthian Bell, Bart., F.R.S.
13. Jeremiah Head.
14. Sir Edward H. Carbutt, Bart.
15. Charles Cochrane.
16. Joseph Tomlinson.
17. Sir William Anderson, K.C.B., D.C.L., F.R.S.
18. Alexander B. W. Kennedy, LL.D., F.R.S.
19. E. Windsor Richards.
20. Samuel Waite Johnson.
21. Sir William White, K.C.B.

* Complete with the exception of James Kennedy, John Robinson, Edward A. Cowper, Percy G. B. Westmacott, of whom photos or prints could not be obtained.

monumental example of modern engineering tools and modern engineering practice. The name of Robert Napier is indelibly associated with the progressive development of shipbuilding and marine engineering. Sir Edward Carbutt took an active part, for a great number of years, in the advancement of mechanical art; and Sir William Anderson, a succeeding President of the Institution, is remembered as the first civilian to be entrusted with the entire engineering control of the Ordnance Factories, where he effected important reforms of signal advantage to the country. To complete the category of Presidents who have been intimately identified with the application of steel on an extensive scale, we have Sir William H. White, who for the last two years has guided the counsels of the Institution of Mechanical Engineers. In his Presidential Address of 1899, Sir William gave an admirable *resumé* of progress in shipbuilding, which is well worthy the attention of all who are interested in the development of steel manufacture and of mechanical appliances generally.

We ought to remember that Sir William Siemens suggested, in 1887, the utilisation of the Niagara Falls for the purpose of generating electricity, and it is interesting to observe that the practical realisation of that vast scheme involved the employment of forgings, the execution of which would probably have been impossible but for the Whitworth system of fluid compression and the Whitworth forging press. As Dr. Coleman Sellers has truly said. "The plant of the Niagara Falls Power Company offers evidence enough of the remarkable progress that has been made, not only in the mechanical arts, but in the high scientific ability required to design machines that had no precedent in size or in exact requirements as expressed in the specifications." Pessimists who tell us that this country is being entirely outclassed by the United States may appropriately be reminded that the undertaking of this important achievement was directly due to the initiative of one who had made England his home, and that its inauguration was only rendered possible by the inventions of another distinguished British engineer. British and American engineers have, however, much to learn from each other, and ample evidence of cordial co-operation was afforded during the past year by the gathering together of engineers representing the Mother Country and the United States at the Institution of Civil Engineers, the Institution of Mechanical Engineers, and at the aunual meeting of the Iron and Steel Institute. During the last-mentioned, a typical and most important announcement was made by Mr. Talbot, of the Pencoed Steel Works, relating to a modification of the open-hearth process, which, in the opinion of several eminent metallurgists, will constitute the greatest advance that has been made for many years. By the Talbot process we are led to anticipate the continuous production of the Bessemer and the yield of the open-hearth system, and to expect a great economy of metal and fuel concurrently with a largely augmented output.

In looking back upon the history of the century just completed, we cannot help being struck by the large number of gifted men who have contributed so much to its unprecedented record. Yet, as John Fritz remarked on a recent occasion, these men have had to endure "trials, troubles, disappointments, mental anxiety and bodily toil in the perfection and introduction of their inventions, besides suffering the sneers and jibes of those who imagine that an inventor is nothing but a wild enthusiast, and treat him accordingly." The reluctance to entertain any new thing has nowhere been stronger than in this country of our own. British engineers and toolmakers have persevered in their attachment to old ways—sometimes with good reason, but in others without such justification; British workmen have persistently set their faces against any kind of improvement; and the great British public has always endeavoured to suppress any exceptionally useful invention.

Engineers of the present day have far greater educational advantages than were open to their predecessors, and the Institution of Mechanical Engineers has performed invaluable work by means of the Research Committee, established in

the year 1879 at the initiative of John Robinson. Tool-makers have also learnt some useful practical lessons from American competition, with the result that an evident desire to make tools in compliance with the necessities of the day has taken the place of the older notion that engineering practice ought to conform with the convenience of the tool-maker.

One essential characteristic of the present day is the growing tendency to specialise industries of every kind. In the good-old days, when there was little competition, "general" engineering shops abounded, where work of almost any kind would be undertaken. Some of these still survive, but they are rapidly giving place to shops filled with modern automatic tools, specially devised for the one particular class of work to be negotiated. The more abundant manufacture and appreciation of automatic labour-saving tools, adapted to the requirements of individual industries, may justly be regarded as one of the most hopeful signs of recent progress.

A few examples typical of recent advances in the construction of such tools are illustrated and briefly described in Figs. 26 to 40, but it will, of course, be understood that this selection most inadequately represents the infinite variety in which tools of precision are produced in the present day.

The high state of development exhibited in steam, gas, and oil engines, both as regards accuracy of workmanship and approach to theoretical efficiency, is well known to everyone, and needs no detailed reference. But this satisfactory condition could not have been attained without mechanical aids of equally accurate construction, and the same remark applies to the wonderfully ingenious—and one may almost say intelligent—machinery which is now applied to various arts and manufactures, and notably in the textile and printing industries.

With the great achievements of modern engineers this article does not profess to deal, but it may appropriately be observed that in all such undertakings the aid furnished by the mechanical engineer is distinctly to be traced. The engineer dredges rivers and waterways, makes harbours and docks, and carries iron roads across the earth or buries them deep beneath its surface. He builds mighty dams across hitherto unconquerable rivers, converts inland cities into seaports, makes lakes where there was dry land, creates new provinces by pushing back and keeping at bay the restless ocean, and even dares to cut up continents into islands. For all these things he is justly honoured; but the world does not always join him in recognising the immensity of the debt that is owing to the genius of the mechanician and to the skill and unremitting care of the contracting engineer. Similarly, the world is apt to forget the mechanical engineer, when lost in wonder at the sight of some sea-going fighting machine, or of some huge floating palace which traverses the ocean with the speed and regularity of a railway train; or of some stupendous bridge, or of some fairy-like palace of steel, under whose roof the population of a great city might be gathered.

Even thoughtful people do not invariably reflect that the scientist is largely dependent on the mechanician for the means of enquiring into the mysteries of outer space and of probing into the hidden secrets of material substances. The mechanical engineer helps the miner to explore the inmost recesses of the earth, and to bring forth her hidden wealth; he helps the husbandman to till and sow the land, and to gather in the fruit thereof in the appointed season. He aids the electrician in calling forth and in applying the wondrous power of electricity to the service of man, and gives to the world many of those things which tend to promote friendly intercourse amongst her sons, and to prepare the nations for the dawn of that era when the arts of war shall be forgotten, and peace shall reign triumphant.

W. H. Worthington

A Century of Iron and Steel.

By BENNETT H. BROUGH, A.R.S.M., F.G.S., Secretary Iron and Steel Institute.

As the Eighteenth Century closed, a new era in the metallurgy of iron had already begun. Attention had been directed to the substitution of machinery for hand labour; Abraham Darby, of Coalbrookdale, had introduced the use of coke in the blast furnace, and succeeded in raising the quantity of iron smelted to 20 tons a week; James Watt had in 1770 perfected the steam engine; Huntsman in the same year had made cast steel; and Henry Cort had in 1784 invented puddling. Nevertheless Great Britain's production of pig iron at the dawn of the century did not exceed 150,000 tons annually. Since then improvements in the methods of mining and smelting iron ores have followed in rapid succession, with the result that the world in 1899 produced no less than 39,000,000 tons of pig iron, the result of the smelting of 85,000,000 tons of iron ore. The iron industry has attained a position that was not dreamt of at the beginning of the century, although even at that date Fourcroy, the celebrated French Minister of Instruction, used words that have characterised the whole epoch:—"L'art de fer, dans ses divers degrés de perfectionnement, marque exactement le progrès de toute civilisation." Indeed, progress in the metallurgy of iron is so intimately connected with the progress in modern civilisation that the consumption of iron computed annually per head of population gives the best measure of the industry, wealth and power of the countries of the world. Considered in this way, Great Britain has been the first manufacturing nation in the world throughout the century, and no other country has occupied so conspicuous a position in the manufacture of iron and steel.

It is during the second half of the century that the development of the iron industry has been most remarkable. In 1854 Mr. J. K. Blackwell gave the following as the world's production of pig iron:—

	Tons.	Per cent.
United Kingdom ...	3,000,000 ...	50·0
France	750,000 ...	12.5
United States ...	750,000 ...	12·5
Germany	400,000 ...	6·6
Austria	250,000 ...	4·3
Belgium	200,000 ...	3·3
Russia	200,000 ...	3·3
Sweden	150,000 ..	2·5
Other Countries ...	300,000 ...	5.0
Total	6,000,000 ...	100·0

In 1899 the world's production of pig iron was as follows:—

	Tons.	Per cent.
United States ...	13,621,000 ...	34·6
United Kingdom ...	9,305,000 ...	23·6
Germany and Luxemburg	8,142,000 ..	20·7
France	2,567,000 ...	6·5
Russia	2,223,000 ...	5·6
Austria-Hungary ...	1,427,000 ...	3 6
Belgium	1,036,000 ...	2·6
Sweden	532,000 ...	1·4
Spain...	296,000 ...	0·8
Canada	94,000 ...	0·2
Japan...	58,000 ...	0 1
Bosnia	15,000	
Italy	8,000 ...	0·3
Other Countries ...	86,000	
Total	39,410,000 ...	100·0

Reference to the Presidential Addresses delivered by Sir William Roberts-Austen before the Iron and Steel Institute, in which he has reviewed in a masterly manner the efforts made during the century in connection with iron and steel, will show that the changes that have been effected in these industries have been so great that it is impossible here to give more than the broadest general outline of the more striking results obtained. The great inventions of the first half of the century in chronological order were briefly as follows:—In 1818 Samuel Rogers substituted iron bottoms for the sand ones used by Cort in the puddling furnace. In 1820,

wood was replaced by malleable iron for colliery rails mainly through the efforts of Birkenshaw. In 1828, Neilson patented the application of the hot blast to furnaces. In 1831 the German metallurgist, Faber du Faur, conceived the idea of utilising the waste gases of the furnace for heating the blast. Aubertot had already, in 1811, made a successful effort to utilise the waste gases at his works in France. In 1839 the use of manganese in steel-making was introduced by Josiah Marshal Heath, whose death in 1851 was hastened by the anxiety and difficulty in which he became involved in attempting to maintain his patent rights. In 1842, Nasmyth perfected the single-acting steam hammer.

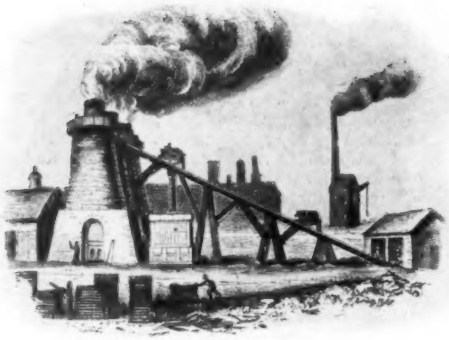
Other improvements were made, notably in the hot-air stoves and calcining kilns, in the size and construction of the furnaces, and in many other respects, so that at the middle of the century the average weekly production of the kingdom had risen to 100 tons per furnace.

At this period all the materials were conveyed in wheelbarrows and thrown into the furnace at its mouth. Where there was a regular incline from the kilns to the furnaces, the loaded barrow was rolled directly to the furnace top; but in a flat country the barrows were placed on stages in a horizontal position, and drawn up an inclined plane, as on the illustration on next page, which represents some furnaces near Hanley, in Staffordshire, described by Tomlinson. The sight then to be seen on a dark night has been picturesquely described by Mr. Daniel Jones :—

"Travelling from Birmingham to Wolverhampton on a dark night about this period, one became conscious of being surrounded with a wild and brilliant scene—the country was apparently in uncontrolled flames; tongues of flame from 150 blast-furnaces licked the sky, for then the economist had not completed the utilising of the waste gases. Two thousand puddling furnaces sent forth their flames, whilst hundreds of mill furnaces, cupolas, air furnaces, and other flame generators, and thousands of pit-fires dotted over the country, illuminated the scene. Open coke fires burnt with sombre sullenness as compared with the brilliant brightness of the furnaces. The white light of the rows of street lamps helped to complete this amazing scene—a scene rendered more astounding from the constant change and activity; the dampers of furnaces being alternately closed and raised, the opening of furnace-doors and trollying of the incandescent piles to the rolls, or puddle balls to the squeezers or helves; red worms of bar-iron passing through the guide-rolls, men stripped to the waist moving to and fro, together with the whirling movement of the train through the district, screeching as it approached a signal-post as though it were escaping horror-stricken from a prairie fire, each minute bringing a change of scene, and yet one of a continuous conflagration. Having reached his destination and collected again his wits, there could be but one impression left on the mind of the traveller who had witnessed the scene—that he had found a veritable pandemonium, fit for Satan, 'gorgons and hydras, and chimeras dire.'"

With the year 1851 there began the most important decade in the history of the iron trade. The first International Exhibition was held in that year. The Crystal Palace erected in Hyde Park was itself the most remarkable illustration of the development of the iron industry and

JOSIAH MARSHALL HEATH, INVENTOR OF THE USE OF MANGANESE IN STEEL MAKING, AND FOUNDER OF THE FIRST EAST INDIAN IRONWORKS.



BLAST FURNACE AT HANLEY IN 1850.

of the use of iron as a structural material. At this Exhibition the importance of steel was first made manifest. Alfred Krupp, of Essen, achieved the greatest success with the largest ingot of cast steel ever before shown, weighing 2,150 kg. Another noteworthy feature of the Exhibition was the collection of British iron ores shown by Mr. S. Blackwell, of Dudley, who subsequently furnished Dr. Percy with funds for their analysis. This exhibit led to public attention being directed to the Liassic iron ores of the Cleveland district, the basis of the Middlesbrough iron trade. Galvanised iron was another novelty exhibited for the first time. A general impetus to trade followed the Great Exhibition, and metallurgy received its share of attention. Not the least important among the results of the Exhibition was the pioneer work started in technical education by the establishment of the Royal School of Mines in 1851.

On August 11th, 1856, Bessemer gave to the world the description of the process that bears his name. The discovery of the means of rapidly and cheaply converting pig-iron into steel by blowing a blast of air through the molten iron was the result of ten years of labour and experiment. Prior to this invention the entire production of steel in Great Britain did not exceed 50,000 tons annually, and its price, which ranged from £50 to £60 a ton, precluded its use for most of the

BLACK COUNTRY BLAST FURNACES IN 1850.

purposes to which it is now applied. At the time of Sir Henry Bessemer's death in 1898, the world's production of steel made by his process had reached the enormous total of 11,215,000 tons yearly, Great Britain alone producing 1,845,000 tons. Its selling price was reduced to £4 10s. a ton. No discovery has had such remarkable results. It is no exaggeration to say that without the Bessemer process the present railway system of the world would not now exist. The most remarkable feature of the invention is, that in all the essential particulars, the process remains identical with that first developed by Bessemer at Sheffield. Valuable help was afforded in the early days by Menelaus and Edward Williams at Dowlais, and the brilliant success achieved was in no small measure due to the work of G. F. Göransson in Sweden, who by increasing the area of the tuyeres succeeded in producing sufficient heat in the converter to allow of the proper separation of slag; and to that of Mushet, who patented the application of spiegeleisen. Moreover, rapidity of working was facilitated by the use of the system of changing the converter bottom and by the plan of making the body of the converter removable from the trunnion belt invented by the great American metallurgist, Holley.

A few years later Sir William Siemens' open-hearth process of producing cast-steel by dissolving wrought iron scrap in molten cast-iron on the bed of a reverberatory furnace was introduced, and became a practical success in the hands of Martin of Sireuil. Siemens afterwards worked with the ore process, in which a part of the scrap was replaced by hæmatite. The high temperature required in this process for the melting of large quantities of steel is obtained by the regenerative furnace, which invention alone would make the name of Siemens ever memorable. As the century closes, one of the most striking features in connection with steel manufacture is the advance in the production of open-hearth steel. In the United States the demand for Siemens-Martin steel is so great that practically no new Bessemer converters are being built.

THE BESSEMER GOLD MEDAL, AWARDED BY THE IRON AND STEEL INSTITUTE.

In their original forms, both the Bessemer and Siemens processes were only applicable to ores practically free from phosphorus. The researches of Snelus showed, however, that phosphorus could be removed by the use of lime or dolomite as a lining and as a flux. This principle was applied on a practical scale in 1879 by Thomas and Gilchrist, and with

SIR C. WILLIAM SIEMENS.

SIDNEY GILCHRIST THOMAS.

THE SEVENTH DUKE OF DEVONSHIRE.
From a Portrait by G. F. Watts, R.A., in the Fitz-William Museum, Cambridge.

the co-operation of E. Windsor Richards and E. P. Martin this basic process, which has completely changed the condition of the world's iron and steel trades, was successfully adopted in practice.

In 1869 the Iron and Steel Institute was founded, and it soon became apparent that there was a desire among the members to add unreservedly to the general stock of knowledge. The willingness to be enrolled in its ranks was not confined to British ironmasters, but extended itself to Continental and American metallurgists, and after the first Continental meeting held at Liége, in 1873, the Institute acquired the cosmopolitan character it has since retained.

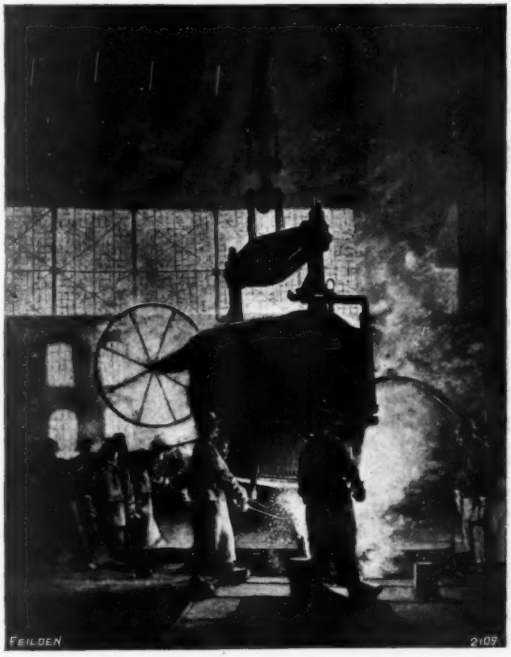
The Duke of Devonshire was the first president. He, to borrow the words of the present president, "worthily sustained the honour of the name of Cavendish, one of the most illustrious in the annals of our country, and the connection of the Duke with the iron industry of Barrow is an incident of first importance in our industrial records. It is certain that the main efforts of his life were directed to developing the resources and improving the condition of the people. Neither rank, wealth, nor intellectual gifts had power to affect the simplicity of his character or to lessen the deep sense of duty which controlled his actions." Since the foundation of the Iron and Steel Institute, all important inventions connected with iron and steel have been recorded in the pages of the Institute's Journal, which has become, thanks to the spirit of voluntary interchange of thought and experience animating the members, a storehouse of information of increasing value.

A few of the recent attempts and achievements that stand out prominently in the records of the Iron and Steel Institute may be cited. The difficulty of obtaining sound ingots in the newer processes of steel-making, a problem dealt with by Sir Joseph Whitworth in 1865, has been obviated. Improvements in forge and mill machinery have been devised, either in the direction of simplification, or by the addition of mechanical gear for manipulating the heavy masses.

Hot blast stoves have been much improved in design. Gas firing has been adopted in reheating furnaces for rolling mills. Soaking pits, invented by Gjers, allow finished steel to be produced with no other fuel than that consumed in smelting the ore in the furnace. Ingenious instruments for measuring high temperatures have been devised by Siemens, Le Chatelier, Roberts-Austen, and Wibórgh. The waste gases of blast furnaces have been utilised, either as sources of heat or even directly in gas engines of 600 horse-power and more. Electric motors have been introduced for driving rolling mills and for charging open-hearth furnaces. A simple means of desulphurising iron has been afforded by the use of mixers holding as much as 200 tons of molten metal. William Garrett, in Illinois, has succeeded in rolling wire rods direct from 4-inch billets, with their initial heat, instead of allowing them to cool down. Important modifications of the open-hearth process have been introduced by Bertrand and Thiel, by Daelen and Pszczolke, and by Benjamin Talbot, at Pencoed. The last, which promises to be the most important, consists in working a 75-ton furnace continuously instead of intermittently.

With new and cheaper processes of manufacture, new uses have been found for steel. In the United States it is being applied in the construction of large buildings. Thus, the structural work of the hotel built for Mr. J. J. Astor, in New York, consists of no less than 10,000 tons of steel. In collieries, steel girders are being substituted for timber props; and on railways, steel waggons are taking the place of wooden ones.

New properties have been developed in steel by the addition of small quantities of silicon, manganese, chromium, tungsten, and nickel. Alloys of iron and chromium were prepared by Berthier in 1820, and by Brustlein in 1877; of iron and nickel by Faraday in 1820, by Marbeau in 1884, and by James Riley in 1889. In France Valton, Gautier, Pourcel, and Jordan developed the manufacture of ferro-manganese, whilst in 1889 Hadfield produced steel containing 7 to 21 per cent.



CASTING OPEN-HEARTH STEEL AT KRUPP'S WORKS.

of manganese and possessing a wide field of usefulness. The use of nickel steel is rapidly increasing. It is largely used for armour plates, and steel wire containing 25 to 30 per cent. of nickel is being made for electrical resistance purposes. The increasing application of these alloy steels confirms the accuracy of the view enunciated by Sir William Roberts-Austen that the main characteristic of the metallurgical work of the century is the inter-

ALFRED KRUPP.

dependence between minute quantities of matter and the masses in which they are hidden. "The metallurgist," he writes, "by adding small amounts of matter to iron, has literally made it possible to change the aspect of the world. He has enabled such structural triumphs as the Eiffel Tower and the Forth Bridge to be constructed; he has created the Age of Steel, and of this age the palaces of the Exhibition of 1900 on the banks of the Seine are the exponent, both as regards their construction and their contents."

In short, the metallurgy of iron is no longer an empirical art. Thanks to the experimental researches of Sir Lowthian Bell and the Austrian metallurgist, Peter von Tunner, the limits of reducing activity in blast furnace gases have been determined, and a useful test of the working condition of furnaces afforded. The production capacity of furnaces has consequently been enormously increased. At the beginning of the century furnaces were producing about 20 tons a week; at the end of the century Mr. Andrew Carnegie, in America, can boast of a furnace that produces 748 tons in a single day. The high position of the iron and steel industries of to-day is undoubtedly largely due to the application of chemical and physical researches. In one year at Krupp's Steel Works at Essen there were made 15,489 chemical analyses and 106,000 physical tests. With the century's advance in practice, the knowledge of the properties of iron and steel has been added to in a remarkable manner by the experimental investigations of Lowthian Bell, Abel, Roberts-Austen, Hadfield, Stead, Sorby (the pioneer in micro-photography), Arnold, Harbord, and many others in this country; of Von Jüptner in Austria, of Osmond and Le Chatelier in France, of Wedding in Germany, of Akerman and Brinell in Sweden, and of Howe in the United States. In the literature of iron and steel the century leaves on record the classic works of Howe, of Percy, Bauerman, and Roberts-Austen, of Gruner, Rivot and Jordan, and of Wedding, Ledebur, and Dürre.

No event in the metallurgical history of the century has been more remarkable than the career of Alfred Krupp, the great German ironmaster. Born in 1812, he was the son of Friedrich Krupp, the founder of the works that still bears his name. The beginning of the Essen Works was exceedingly humble, and in 1819 new works were built for the manufacture of crucible steel, the daily production being 400 lbs. of steel. Pecuniary difficulties were encountered, and in 1825 the Krupp family had to give up their house in the town and move into a miserable one-storeyed cottage at the works, where, in 1826, Friedrich Krupp died Alfred Krupp was then a lad of fourteen, the works were encumbered with debt, and only four men were employed. Under his vigorous control, however, these works became the largest in the world. From the date of his success at the London Exhibition of 1851, the progress of his works was rapid; until at his death in 1887 the works afforded employment to 20,960 men and supported a population of 73,769 souls. This striking instance is typical of the increased activity manifested of recent years throughout the iron and steel industries.

Bennett H Brough

The Trade of the Century:

A Retrospect and a Forecast.

By JOHN B. C. KERSHAW, F.S.S.

And yet we are nearing an epoch of no common kind, short indeed in the lives of nations, but longer than the life of man, when we may well pause to take stock. Within six weeks we shall have closed the Nineteenth Century, and have entered on a new one for better or for worse. It is, of course, only an imaginary division of time, though it seems solemn enough, for we are on a pinnacle of the world's temple where we can look forward or look back.
LORD ROSEBERY at GLASGOW, Nov. 16.

But the question still remained: Are we holding our own? In answering that question we found ourselves confronted by two new factors, the emergency of which was the cardinal point in the history of national trade during the last half century. I refer to the stepping out from the rear to the front ranks of Germany and of the United States of America. So far from enjoying the undisputed hegemony which was so confidently predicted for British trade fifty years ago, there is not now an inch of ground in any one of the international markets for which we are not fighting with all our available strength.—Mr. ASQUITH at LEEDS, Nov. 23.

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I. INTRODUCTION.

FOR the majority of the English-speaking race, midnight on the 31st of December, 1900, marks the close of the nineteenth and the dawn of the twentieth century. The German Emperor, with that true imperial instinct which has ever distinguished him, has, I admit, decided that the nineteenth century ended on December 31st, 1899. Those who read the heated correspondence in *The Times* on this subject in December, 1899, will appreciate the significance of this action, and will be ready to agree that it is at times useful to possess an Emperor able and willing to settle off-hand questions so disturbing to the mental balance of the average man and woman. This decision, as a witty German lady pointed out to the writer, places Germany twelve months ahead of all her industrial competitors in the new century, and may be regarded as but another instance of the care and forethought of the Emperor for our Teutonic cousins' welfare.

But whether the twentieth century be held to commence upon the 1st of January, 1900, or upon the 1st of January, 1901, the decision is without weight for the purposes of this article. Either date will suit equally well as the standing point from which to review the industrial progress of the century which has just closed, and the industrial prospects of our country in the century upon the threshold of which we stand.

To the future historian the nineteenth century will be known as the century of coal and steam. Steam-power has revolutionised all industrial operations, and has led to the substitution of the factory system of manufacture for home and cottage industries. The possession of extensive and cheaply worked coal-beds has been the chief factor in this industrial change, and to the early development of her coal resources England owes her present position at the head of the manufacturing nations of the world.

In the year 1801 the total import and export trade of the United Kingdom was valued at £55,000,000. In 1899 this total had grown to £740,000,000, or thirteen-fold; although the population is estimated to have only increased from 16,345,000 to 40,800,000 in the same period of time. No other country in the world can show such a growth in industrial wealth and importance in the nineteenth century.

In the following pages an attempt will be made to trace this growth through its various stages: to analyse some of the causes which have led to severe fluctuations in the value and volume of our trade: and finally to estimate the extent and strength of the forces which are operating to retard our industrial progress

as a nation in the century upon which we have just entered.

For the purposes of this article all the figures have been thrown into diagrammatic form, and the results are presented in Diagrams I., II., III., and IV. This is the most scientific method of using series of numbers that show marked variations from year to year, and it is the only one which enables the real extent and significance of these variations to be grasped.

II. THE GROWTH IN THE TRADE OF THE UNITED KINGDOM DURING THE FIRST HALF OF THE CENTURY, 1801-1853. (See Diagram I.)

Diagram I. is based upon the official returns for the first half of the century, the figures for population, imports, and exports being shown as three lines, in the one diagram.

It may be explained here that up to the year 1853 the authorities used what were known as "official values" in calculating the totals for the "import" and "export" trade. These "official values" were fixed in 1694, and their relation to the "real" value of the commodities imported or exported of course varied from year to year.

The following table shows the relation between the "real" and "official" values of the exports for the five decennial periods between 1801 and 1850:—

Period.	Official Value.	Real Value.
1801–1810	100	147·4
1811–1820	100	116 7
1821–1830	100	74·9
1831–1840	100	56·6
1841–1850	100	43·6

On this account the two lines in Diagram I. really represent the progress in the volume of our import and export trade during the first half of the century.

Examining these lines in detail, we see that until 1831 there was little expansion in the external trade of the United Kingdom. The aggregate value of the import and export trade in that year was only £109,000,000, the population at this date being 24,392,000.

From 1831 onwards both imports and exports show considerable increase; but the latter grow the more rapidly, and from 1842 onwards show a most striking upward movement. This is the period of our real rise as an industrial nation; and this expansion of our export trade marks the improvement of the steam-engine as a power generator, and the dawn of the factory system of manufacture.

It is true that the steam-engine had been greatly improved by James Watt between 1769 and 1782, and had at the latter date been successfully employed for pumping purposes. In 1800, also, a further step in advance was made by the application of steam-power for driving the looms in the textile industries of the North. But it was not until the middle years of the century that the steam-engine had been generally adopted for generating the power required in our staple industries, and that the great expansion of our foreign trade commenced.

It was perhaps natural and inevitable that those who had been foremost in their efforts to remove all protectionist duties from food-stuffs and raw materials entering the United Kingdom should have regarded this wonderfully rapid growth as the direct consequence of these changes in our fiscal system, or that they should have prophesied uninterrupted prosperity for our country so long as these principles were upheld. The enthusiasm with which Free Trade principles and the doctrines of the Manchester school of political economists were regarded in the fifties and sixties, is, however, now extinct, and most of the younger students of this question are prepared to admit that our Free Trade policy was only *one amongst many causes* which operated to give British manufacturers the leading place in the world of industry in the years of which we are speaking.

In 1853, the last year of the period covered by Diagram I., the aggregate (official) value of our external trade had grown to £337,000,000, of which nearly two-thirds (£214,000,000) was accounted for by our exports, and only slightly over one-third by our imports.

One of the chief features of Diagram I. is the position of the line showing the volume of the imports. From 1814 on-

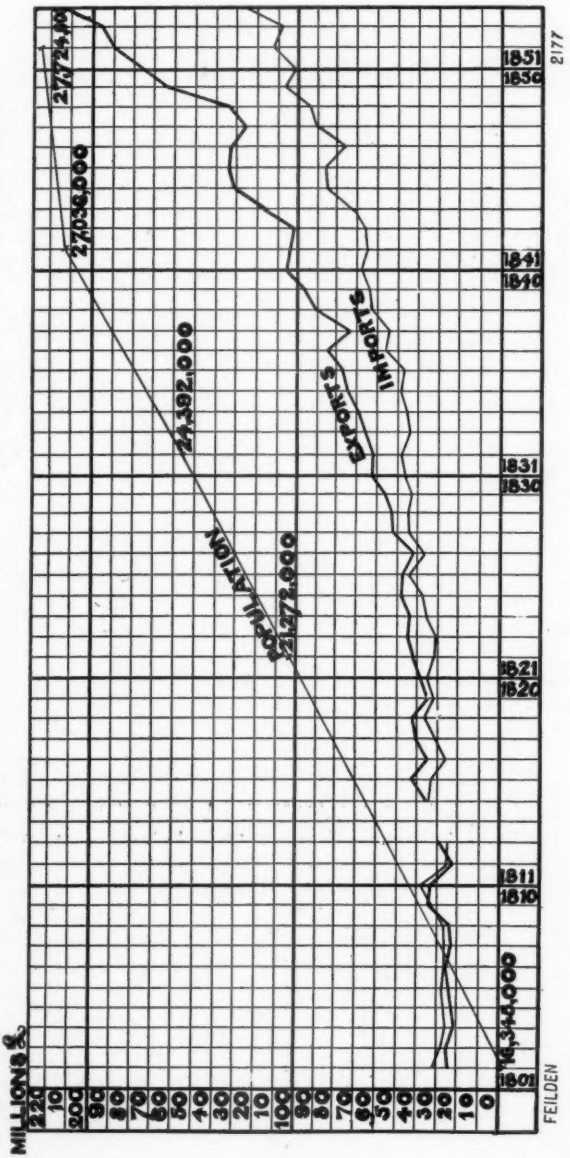


DIAGRAM I.—SHOWING THE EXPORT AND IMPORT (OFFICIAL) VALUES FOR EACH YEAR OF THE PERIOD 1801–53. THE STRAIGHT LINE SHOWS THE INCREASE OF POPULATION DURING THE SAME PERIOD. EACH VERTICAL DIVISION EQUALS TEN MILLIONS STERLING; EACH LATERAL DIVISION ONE YEAR.

wards this line is below that representing the volume of our exports, and the gap between the two increases as we approach the closing year of the period.

The volume of our export trade was, in fact, growing much more rapidly than that of our import trade, and it is only in the second half of the century that this has been changed, and that our imports have increased more rapidly than our exports. The check in the increase of population between 1841 and 1851 is noticeable, and was due to the potato famine in Ireland, and to the consequent decrease in the population of that division of the United Kingdom. There were also great losses from a cholera epidemic in 1848-49 which helped to check the increase of population.

III. THE GROWTH IN THE TRADE OF THE UNITED KINGDOM DURING THE SECOND HALF OF THE CENTURY, 1852-99. (See Diagram II.)

The figures upon which the lines in Diagram II. are based, represent "real" values, and comparisons between the two diagrams, or between specific years before and after the year 1853, are therefore impossible. Further changes were introduced by the authorities into the method of estimating the values of export

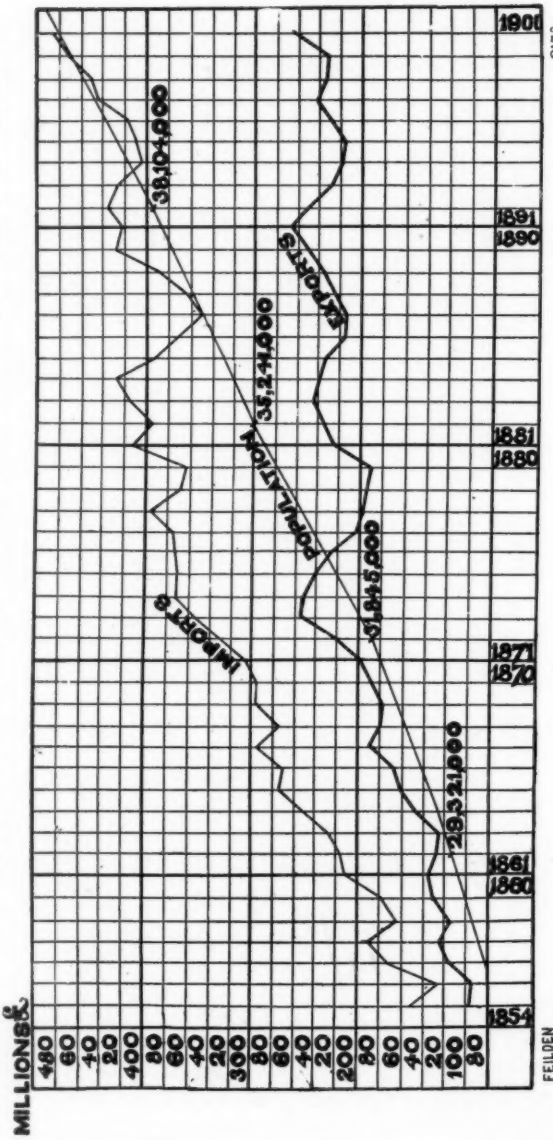


DIAGRAM II.—SHOWING EXPORTS AND IMPORTS (REAL) VALUES FOR EACH YEAR OF THE PERIOD 1854–99. THE STRAIGHT LINE SHOWS THE INCREASE OF POPULATION DURING THE SAME PERIOD. EACH VERTICAL DIVISION IS EQUAL TO TWENTY MILLIONS STERLING; EACH LATERAL DIVISION ONE YEAR.

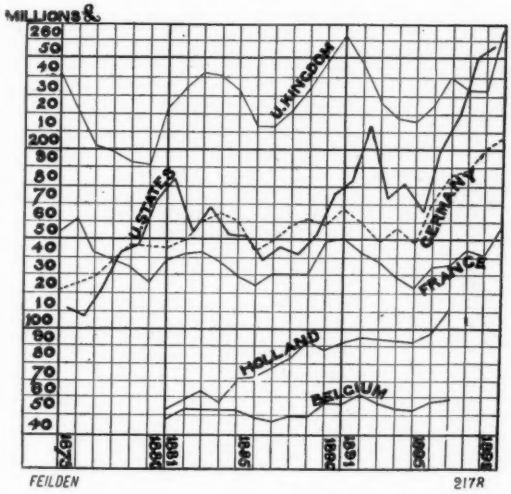
and import commodities in 1870, and comparisons before and after this latter date are also untrustworthy. Studying Diagram II. with these two cautions in one's mind, we see that its chief feature is the gap between the export and import lines. The aggregate value of the imports has shown a more steady expansion than that of the exports; and for the whole period covered by the diagram the growth of our import trade has shown a tendency to keep pace with the increase of population, while that of our export trade has not been so satisfactory.

Up to 1872 the value of our export trade showed steady progress. Since that year the value of this trade has fluctuated about one level, viz., £230,000,000, and not until 1899–1900 has any marked progress been manifested. If expansion similar to that evident in the value of our import trade had taken place, the value of our export trade in 1900 would have been nearly £400,000,000.

The chief causes of this non-expansion in the value of our export trade during the closing quarter of the century are, a great fall in values of manufactured goods, and increased foreign competition. The latter will be discussed more fully in the last section of this article.

IV. THE FLUCTUATIONS IN THE VALUE AND VOLUME OF OUR EXPORT TRADE DURING THE LATTER HALF OF THE CENTURY. (See Diagrams II. and III.)

DIAGRAM III.—SHOWING EXPORT VALUES FOR THE CHIEF EUROPEAN EXPORTING COUNTRIES AND FOR THE UNITED STATES DURING THE LAST QUARTER OF THE CENTURY. EACH VERTICAL DIVISION EQUALS TEN MILLIONS STERLING: EACH LATERAL DIVISION ONE YEAR.



A closer study of the export line in Diagram II. reveals several periods of depression, the two most marked of these occurring in 1872-79 and in 1891-94. Taking the whole line and examining it in detail, one finds similar depressions of shorter duration in 1858, 1861-62, 1867-68, 1883-86, and in 1897-98.

Many ingenious theories have been elaborated in order to account for the regularity with which these periods of trade depression recur, but none of these has yet received general acceptance. It is not possible to discuss within the limits of a magazine article these theories at any length, and a mere enumeration of the causes advanced will have to suffice.

The currency, the money market, sun spots, famines, Protection, Free Trade, bad harvests, trades unions, wars, and Radical Governments, have all been put forward at one time or another as chief causes of these unwelcome fluctuations in our trade. Those interested in the subject will find each of these exhaustively dealt with in past volumes of the Proceedings of the Royal Statistical Society, and of the British Association. It may, however, be remarked that if the line showing the fluctuations in our export trade during the second half of the century be based upon figures representing its volume, many of these depressions disappear, and checks in progress are only to be found in the years 1860-62, 1885, 1891-93, and in 1897-98. Diagram III. has been based upon such a series of figures; index numbers having been used to reduce the total exports value in each year of the period to the prices ruling in 1881. The severe depression of 1873-79, when allowance is made for the fall in values, is seen to have been only a period of *non-expansion in the volume* of our trade; and it is curious to note that the depressions of 1860-63 and of 1891-93 were really the more important when the volume of our export trade is considered.

Taking the volume of our export trade for the whole century, we find the following periods of depression—1811, 1816-19, 1826, 1837, 1841-42, 1846-47, 1860-62, 1885, 1891-93, and 1897-98.

In an article published recently* I have submitted the theory (first advanced by Sir William Herschell), that there is a connection between these periodic trade depressions and bad harvests, to a detailed examination, and I have stated my belief that there is some degree of truth underlying this theory.

It is probably true that many causes combine to produce these periodic fluctuations in our external trade, and no one theory of their origin can be accepted as a full explanation of their recurrence. Of these causes, bad harvests, weakened credit, and foreign tariff changes, are

* Journal of the *British Economic Association*, Dec. 1900.

the more important. As the vagaries of the weather, and the mental mood of bankers and capitalists, are both beyond Government control, the prospects of our ever being able to prevent the occurrence of trade depressions are remote. However, if prevention is an impossible policy, prevision is not; and I believe that much more might be accomplished by the Board of Trade than at present, in warning and preparing the trading and manufacturing public for these periods of bad trade.

V. THE FUTURE OF OUR COUNTRY AS A MANUFACTURING NATION.

An impartial review of the figures presented in diagrammatic form in this article shows that the wonderful expansion and progress which characterised the middle portion of the century have not been continued to its closing years. I have already alluded to the practically stationary position of our export trade during the last twenty-five years. The following table, showing the annual values of the imports and exports per head of the population, in the successive years of census, is worthy of careful study:—

Year.	Population.	Quinquennial Averages.		Value in £ sterling per head.	
		Imports.	Exports.	Imports.	Exports.
		£	£		
1811	18,547,000*	30,100,000	28,900,000	1·62	1·56
1821	21,272,000	32,060,000	40,160,000	1·51	1·89
1831	24,392,000	46,080,000	62,600,000	1·89	2·56
1841	27,036,000	65,800,000	104,080,000	2·43	3·85
1851	27,724,000	109,840,000	188,420,000	3·96	6·80
1861	29,321,000	216,360,000	132,400,000	7·38	4·52
1871	31,845,000	331,140,000	224,800,000	10·41	7·07
1881	35,241,000	402,200,000	226,000,000	11·42	6·42
1891	38,104,000	422,600,000	240,800,000	11·09	6·32

* Estimated; no census in 1811.

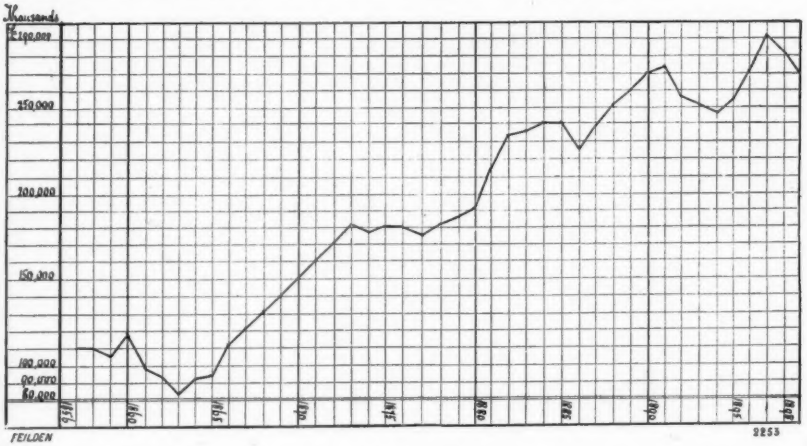
The values per head before and after 1853 (above and below the line) cannot be directly compared for the reason given on the second page of this article; but otherwise the figures show the relative annual values of our imports and exports per head at the various decennial periods. Up to 1851 our exports grew much more rapidly than our population, and the values of the exports per head increased fourfold between 1811 and 1851. In the second half of the century it is the imports which show the greater expansion, the values of imports per head of the population having advanced from £7·38 in 1861 to £11·42 in 1881. The exports show no such satisfactory increase. They advanced, it is true, from £4·52 to £7·07 per head between 1861 and 1871; but since the latter year there has been a steady fall, and in 1881, and again in 1891, the value of the exports per head of the population shows a marked decline.

These figures can only be understood by a study of the industrial progress of Germany and the United States, for it is chiefly due to the competition of these two countries that our progress has suffered such a severe check in the closing years of the century.

In 1898, for the first time in her industrial history, the United Kingdom had to relinquish the first place to the United States as regards the value of the export trade, and it is now certain that the figures for 1899 will repeat this phenomenon.

For the purpose of showing the relative changes in the position of the six chief exporting countries during the last quarter of the century, Diagram IV. has been prepared. A study of this diagram is recommended to those whose faith in worn-out dogmas has led them to the comforting belief, that our position as a

DIAGRAM IV.—SHOWING THE VALUES OF THE EXPORTS OF THE UNITED KINGDOM FOR FORTY-THREE YEARS (1856-98) IN MILLIONS OF POUNDS STERLING, AT THE PRICES OF 1881. THE TOTALS THUS OBTAINED THEREFORE REPRESENT THE FLUCTUATIONS OF THE VOLUME OF OUR EXPORT TRADE.



manufacturing nation was permanently secured.

In 1875 the value of the export trade of the United Kingdom was double that of its chief rivals, Germany and the United States; and France stood second in the list of exporting countries. In 1899 the United States heads the list, with the United Kingdom second, and Germany closely in her rear. In the intervening years what do we see? The export trade of three countries increasing by irregular movements—namely, that of Holland, Germany, and the United States: and the export trade of Belgium, France, and the United Kingdom practically stationary or declining.

It is therefore certain that it was to a combination of causes, of which the adoption of a Free Trade policy was only one, that we owed the wonderful expansion and progress of the middle years of the century; and now that some of these causes have ceased to operate, our industrial supremacy is being successfully assailed. The opinion frequently expressed by leading political economists twenty or thirty years ago, that no Protectionist country could hope to compete with us in the open markets of the world, is proving fallacious. Opinions founded on insufficient data usually are fallacious. Our most dreaded and successful rivals are both Protectionist countries. That the competition which we now have to meet in all the markets of the world will increase in severity is also certain. In a Report, prepared by Sir Courtenay Boyle in 1896,* it was shown that the manufacturing populations of Germany and of the United States were growing more rapidly than our own. As a natural consequence of this it follows that the supplies of manufactured goods to be disposed of in the outside markets of the world must increase. We have already lost the first place to the United States, and many believe that it will not be long before we have to relinquish the place which we now occupy in the ranks of the exporting countries, to Germany. But while admitting that this change of position is a result of natural law, and is therefore inevitable, we must guard against taking a too gloomy view of our country's position. While our coal lasts and can be worked at a reasonable cost, we possess an asset of inestimable value. The fear that the waterfalls of France,

* Memorandum upon the Export Trade of the United Kingdom, United States, France, and Germany. *Board of Trade Papers.* 1896.

Switzerland, and Norway will render this asset of little value is due to lack of knowledge. The nineteenth century has been the century of steam-power. Electricity, not steam, will be the universal power-agent of the century just born. But electricity can be generated from coal—with modern plant and machinery—almost as cheaply as from any of the larger waterfalls in Europe or America. In Norway, it is true, electrical power can be generated at a very low cost. But the economic advantages of a waterfall in Norway, as compared with a coal-pit in South Lancashire, are largely discounted by its distance from the markets of the world for the raw materials and for the manufactured products.

The possibilities of utilising the energy stored up in coal in new ways are also great. The problem of power generation from the waste gases of blast furnaces has been solved in a practical manner in Germany and in Belgium; and a new form of gas producer in Germany has nearly doubled the thermal energy which can be extracted from 1 lb. of coal.

If our manufacturers will but make use of every advantage that applied science can offer to them for increasing the efficiency of their works or factories; and if our workers will second these efforts of their employers by doing all in their power to obtain the maximum of output at the minimum of cost, we may hope in the new century to maintain, so long as our coal lasts, our position as one of the leading manufacturing nations of the world. And before our coalfields are exhausted we may have realised the dream of a federated Empire. The waterfalls of Canada and the coalfields of South Africa and of Australasia, developed by British capital and by British labour, may then win for the Empire in the coming century a place equal to that held by the mother country in the century which has just closed.

Should our prosperity be further checked, and this natural development of the resources of the Empire be hindered, by a fiscal policy adopted half a century ago, under circumstances widely different from those of the present time, it will be necessary to reconsider that policy, and to inform each of our chief competitors in trade, that we can no longer grant to them the privilege of free entry to all our markets, except as a return for similar privileges in all countries under their flag.

John B. C. Kershaw

The Development of Textile Industry and Machinery during the last Century.

By W. H. WILSON.

THE progress of textile industries and the development of the machinery connected with its production, during the last century, has marked an epoch in the history of British Manufactures, and a rate of advancement which has not been equalled by any other form of the world's industrialism, either in the extent of its production or the almost perfect arrangement of its details.

To such an ideal state of perfection has the several operations been brought that an attempt to describe the whole of the improvements would involve a considerable amount of research and a treatise of indefinite length.

This article may therefore be described as a brief survey of the comparative imports of the raw material, exports of yarn and woven goods, the factory system, and the principal improvements made in spinning and weaving machinery from the middle of the eighteenth century to the present time.

The growth of the industry may be described as phenomenal, as in 1750 we imported 26,576 cwts.; 1800, 500,000 cwts.; 1810, 1,176,767 cwts.; 1820, 1,316,920 cwts.; 1830, 2,321,428 cwts.; 1840, 5,290,072 cwts.; 1860, 12,481,096 cwts.; 1880, 14,541,648 cwts.; 1890, 16,011,350 cwts.; and in 1899, 14,520,399 cwts. Statistics show that in the years 1829–31 the yarn exported was 63,300,000 lbs. out of 216,500,000 lbs. spun, the latter figures representing the product of 10,000,000 spindles, tended by 140,000 operatives working 69 hours per week at an average wage of 10*s*., bringing the cost of labour to 4·2 pence per lb. of yarn.

The period of rapid development from the year 1830 to the present time has not been without some of the reverses which at times crop up to break the continuity of a successful industry, as instance the paralysing effect of the American Civil War in 1860, and the stoppage for a period of 20 weeks by the Oldham lock-out of 1892.

In face of these and other adverse circumstances, the imports and exports have steadily increased, and in the year 1899 were as follows:—Raw cotton imported, 14,520,399 cwts., valued at £27,673,039; export of cotton yarn, 213,288,700 lbs., valued at £8,054,644; export of cotton piece goods, 5,440,551,600 yds., valued at £50,875,853.

In the year 1760 the total number of operatives supported by the whole of the cotton industry numbered 40,000; in 1893 the number of operatives engaged in spinning and weaving mills alone was 530,000; no reliable data are obtainable as to the number now employed, but the number of spindles in 1899 had increased to 45,400,000.

The advent of the textile factories—which in 1787 numbered 143—has undoubtedly brought about a very considerable improvement in the condition of the operatives, who under the modern systems are better educated, housed, clothed, and fed than their forefathers in the beginning of the last century.

There were, however, exceptional branches, as we find from the chronicles of the times that the trade of a weaver was of such importance that the exponents of the craft were accustomed to receive as much as four guineas for a piece of muslin twenty-four yards long; and were so conservative in their manner as to resent any intrusion into their company in the hostelries they patronised, and affected the dress and dignity of gentlemen, bringing home the production of their looms in the full costume of broad-brimmed hats, top boots,

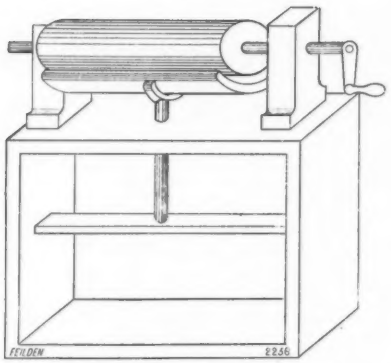


FIG. 1.—LEWIS PAUL'S MACHINE OF 1738.
THE PRECURSOR OF THE MODERN CARDING ENGINE.

ruffled shirts, and silver-mounted canes, and in their own select circle inhaling the fragrant weed from the bowls of long churchwarden pipes.

This was the position of the operative weaver who was contemporary with Crompton's method of spinning.

Let us take a retrospective glance at the progenitors of these aristocrats of the cotton trade.

These were mostly small farmers, who devoted some portion of their time to that section of agriculture which would provide them with a modicum of food-stuffs of the coarser kinds for the family's consumption.

The males were thus engaged, whilst the making of small quantities of butter and cheese was superintended by the female portion of the household.

The remainder of the time was devoted to the preparatory stages of textile production — by the women, carding, slubbing and spinning; while the male members busied themselves at the looms, of which there were generally from three to four belonging to each of these quasi-farmers.

The spinning and weaving, as a supplementary source of income, had its special advantages; it could be followed by each and every one of the family in some capacity or other, as, being a light vocation, all who were in possession of their faculties were enlisted in its service. But what were the returns on this primitive method of manufacture? The father could earn from 8*s.* to 10*s.* per week, and the sons—if any—from 6*s.* to 8*s.*, and to supply them with yarn it took from six to eight pair of hands to each weaver, the earnings of these assistants amounting to about 3*s.* per week each. In the year 1830 there were existing 225,000 hand-loom weavers, and the report of a Parliamentary Committee sitting in 1834 says that many of them were only earning from 2*s.* to 3*s.* per week, working 90 to 96 hours, and subsisting on the coarsest kind of food.

The consumption of cotton goods in Great Britain and Ireland has increased as follows:—

In 1820.....	35,620,000 lbs.	= 1·5 per head.
In 1885.....	201,800,000 lbs.	= 5·3 ,,
In 1893.....	270,000,000 lbs.	= 7·1 ,,

The first textile factory of which we have any authentic record is one erected at Nottingham by Hargreaves, a Blackburn weaver, whose name stands out so prominently in the history of cotton spinning. He, in partnership with one Thomas James, a joiner, erected a two-storey

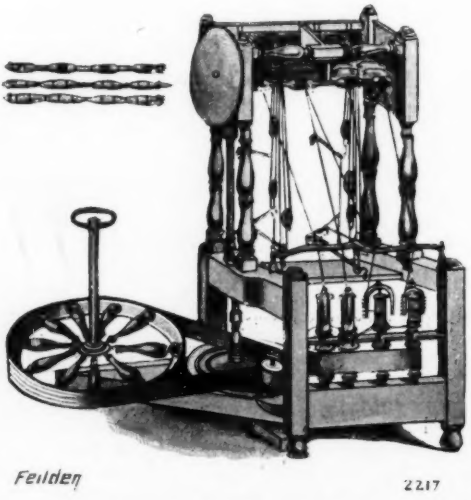


FIG 2.—ARKWRIGHT'S WATER FRAME.

building, but there is no account as to the number of machines placed therein or the rest of the equipment.

Other mills followed at later periods, notably those at Cromford and Matlock by Arkwright, who chose the sites for the purpose of driving the machinery by water power.

In 1780 the first cotton mill was erected in Manchester, but here the motive power was produced by a pumping engine, which drove a water-wheel, the natural surroundings of the locality providing no watercourse that could be utilised for the purpose.

With the improved machinery and the introduction of the steam-engine the evolution of the mills began, and factories sprang up all round the Lancashire district, and as early as 1820–30 we find them with a frontage of 80 yds., and standing five storeys high.

Among some of the older ones may be mentioned those of Messrs. Birley, whose name figures so largely in the Lancashire cotton trade.

The greatest impetus was given to factory building between the years 1860 and 1880, when, perhaps, the greater number of the "Oldham Limiteds" were being erected. That they are too numerous and over-represent the requirements of the industry is a moot point, but the failure to pay dividends in many instances may be ascribed to over-speculation rather than a want of trade. The factory system of the early part of the last century was surrounded with cruelties and indignities that to our present-day ideas seem horrible and inconceivable to the workers of this generation. According to the statements of one of the greatest philanthropists of the time, Earl Shaftesbury, the conditions of the factory workers were almost indescribable. Children—mere babies—were employed from early morn till late at night, and were supplied in most instances by the myrmidons of Bumbledom, and treated in a similar way to the hero of Dickens' immortal novel.

It was not till the year 1819 that anything was done to ameliorate the condition of the oppressed children, whose deplorable state at this period may be judged when Macaulay, speaking of a laborious task, compares it to the work of children in factories or negroes on a sugar plantation.

The initiation of the present Factory Act was due to Sir Robert Peel, a large millowner employing about a thousand children.

He brought in a Bill, which was passed, that no child or person under the age of 16 years should be employed longer than 12 hours a day exclusive of meal times.

In 1825 a further effort was made on behalf of the factory worker by Sir John Hobhouse, who passed a Bill making it illegal to employ any person under the age of 18 years for a longer period than 69 hours per week.

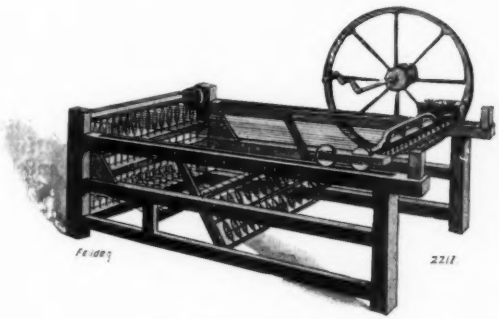


FIG. 3.—HARGREAVES' "JENNY."

It is much to be regretted that these acts, beneficial as they were, were strenuously opposed by the employers, frequently broken, and owing to the negligent system of factory inspection and the obstruction offered, were infringed upon right and left.

The year 1847 saw the introduction of the 10 hours' Bill by John Fielden, which was carried, but not without the most formidable opposition, such benefactors as Cobden and Bright looking upon it as too drastic a reform and one that would be inimical to both masters and workmen, Bright, in particular, denouncing it as a

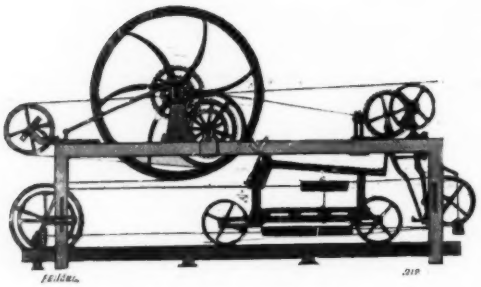


FIG. 4.—THE FIRST "MULE."

measure which, if made law, would be one of the worst ever passed by the Legislature.

That it has been productive of good results cannot be denied, and, as a further proof, the hours were again reduced in 1876 to 56½, this time *without any opposition* from statesmen, economists or employers.

In concluding this portion of the article let us see how the British operative compares with those of other countries :—

In 1891-1893, in Great Britain there were 45,270,000 spindles at work turning out 1,544,000,000 lbs. of yarn with an average of 4·86 operatives per 1,000 spindles working 56½ hours per week with the following rates of pay :—Mule spinners, 36*s.* to 42*s.* per week ; ring spinners, 12*s.* to 15*s.* per week ; weavers, 15*s.* to 27*s.* per week.

Germany, 1891 - 1892. — 6,071,000 spindles turning out 520,000,000 lbs. of yarn, 8·9 operatives per 1,000 spindles working 60-70 hours per week and receiving :—Spinners, 18*s.* to 24*s.* per week ; weavers, 11*s.* to 13*s.* per week ; whilst hand loom weavers averaged from 5*s.* to 6*s.* per week of 96-102 hours.

Russia, 1891-1892. 6,000,000 spindles turning out 360,000,000 lbs. of yarn, 16·66 operatives per 1,000 spindles working 70-84 hours per week and receiving :—spinners, 10*s.* to 18*s.* per week ; weavers, 8*s.* to 14*s.* per week ; head piecers, 6*s.* to 8*s.* per week.

France, 1891-1892. 5,400,000 spindles turning out 280,000,000 lbs. of yarn, operatives working 66-70 hours per week and receiving :—spinners, 16*s.* to 24*s.* per week ; weavers, 10*s.* to 16*s.* per week.

Switzerland, 1891 - 1892. 1,722,000 spindles turning out 60,000,000 lbs. of yarn, 6·5 operatives per 1,000 spindles working 66 hours per week and receiving :—spinners, 17*s.* per week ; weavers, 12*s.* per week.

In comparing the above rates of wages and hours of labour, well may we be proud of the position of the British operative, and agree with the statement of Professor von Schultze Gavernitz, that the operatives in the industrial Germany of to-day are in as poor a condition as the English operatives of 60 years ago, and another authority says that the German operative cannot live at the present time as well as his colleague in England 100 years ago. It is the indomitable perseverance and the untiring energy inspired by the ambition to be at the top, that has placed the British factory worker where he is to-day.

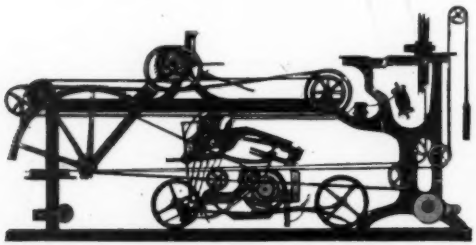


FIG. 5.—ROBERTS' MULE, 1830.

Passing now from the factory system and condition of labour at home and abroad, we next approach some of the principal features in the development of spinning and weaving machinery which, at the beginning of the century, was in a transitory state, as we find that in the year 1838 there were still in existence 200,000 hand looms, the operatives of which were paid at power loom prices, though the ratio of production between the one and the other was as 2·5 to 1.

The initiatory stage of machine spinning may be said to have commenced in 1738, when Lewis Paul in conjunction with one John Wyatt, conceived the idea of producing a fibre of cotton by passing the material between rollers, and this primitive operation may be predicated as the precursor of the modern carding engine. A little departure may be necessary to point out what are the essential principles of the modern card, which is one of the most important of the preparatory machines.

These consist of 1st, continuous feed; 2nd, continuous card surface; 3rd, continuous stripper and coiler.

These functions were existing in Paul's machine, so that it may be said to have been well thought out and designed, though only in a primitive form.

This was in 1747, but prior to this—in 1738—Paul had made a similar machine (Fig. 1), and we find him working at Birmingham by means of horse-power, but owing to a difficulty or obstruction of some kind it was abandoned in 1743. The principal object of Paul's invention was to produce a continuity of fibre in the form of a sliver or rope, and if we imagine for a moment the change in position from the horizontal to the vertical we shall have some idea of the analogy between this and the vertical spindle of the mule.

Some years elapsed, and Paul's invention lay in a dormant condition until 1761, when the Society of Arts gave an incentive to inventors by the offer of a prize of £50 for a machine which would be capable of spinning six threads at a time with one person's attention. This inducement brought out a host of inventions, but none of the methods submitted were considered of sufficient merit to gain the prize.

The next act in the evolution of spinning was the invention of the Jenny (Fig. 3) by Hargreaves, who realised the difficulty of obtaining weft in sufficient quantity, and sought to bring about some method of production whereby a sufficiency of yarn would be obtainable. His efforts, which were to some extent successful, were not appreciated by his neighbours, with the result that he found it expedient to remove to Nottingham, and in the house of a Mr. Shipley, for whom he worked, he set up a number of his machines with vertical spindles, twisting process, and cop-forming arrangement.

A further improvement was made by Arkwright, a barber by trade, somewhat itinerant perhaps in pursuit of his vocation, but possessed of some considerable mechanical knowledge. In 1768 he succeeded in building his water-frame spinning machine (so called because of the motive power used in connection with it),

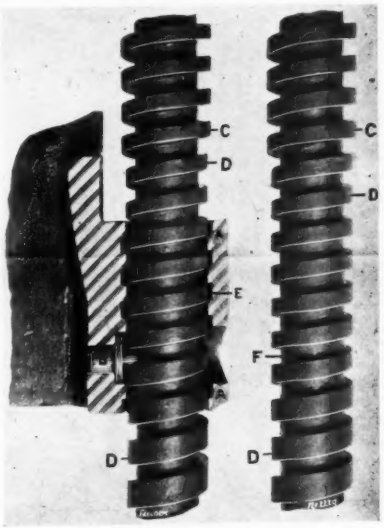


FIG. 6.—DIFFERENTIAL SCREW, MULE QUADRANT.

built up from a heterogeneous mass of wheels, etc., obtained by him during his wanderings among the clockmakers and mechanics of that time. He had, without doubt, seen the several forms of machinery then in vogue, and determined to improve upon them.

The illustration, Fig. 2, shows this water-frame of Arkwright's as it was in work at the Cromford and Chorley Mills, which had been erected to accommodate this type of machine.

We are not prepared to discuss the validity of Arkwright's claims to originality,

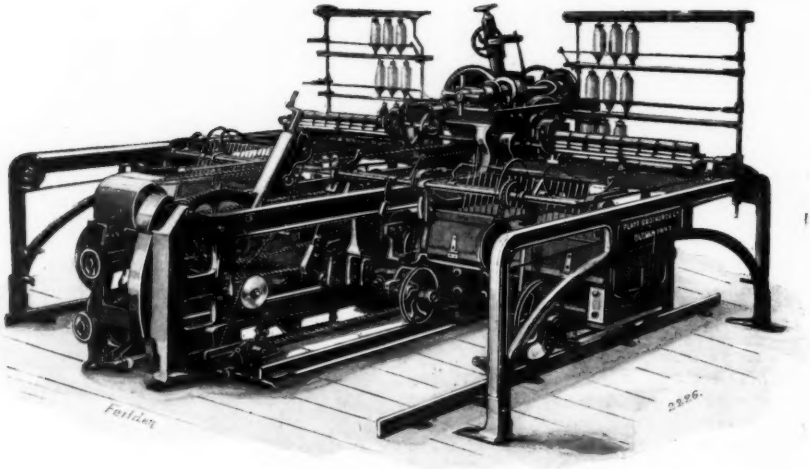


FIG. 7.—A MODERN MULE.

nor dispute the claims of other inventors, or even quote the various law suits he brought in support of his patents, though we may point out the difficulties that would trammel an inventor at that time by referring to the antagonism of the operatives to the introduction of machinery, as we find organised bands going about the Lancashire district demolishing the spinning Jennys of Hargreaves, and destroying every piece of mechanism which, in their misguided opinion, had a tendency to ruin their trade. The frenzy of the operatives was augmented by popular opinion, and the Luddites had become so formidable that a large mill built by Arkwright, near Chorley, was wrecked a few years after by a mob in the presence of a large force of military and police, who were in no way appealed to by the civil authorities to prevent it. It must be remembered that these acts took place when the hand-workers were in a state of semi-starvation, and the poor law officials were prejudiced by the opinion that the existence of the machinery would increase the pauperism.

The next step, and perhaps the most important, as representing a closer approach towards the desired end, was the invention of the mule (Fig. 4), a hybrid between Hargreaves' Jenny and Arkwright's water-frame, the former of which Crompton was using for producing the weft used on his own hand-loom.

Crompton's primary object was to produce a finer yarn, and this he achieved by a travelling carriage, which placed a greater tension upon the thread before the winding commenced. We find that this mule, although it contained many of the essential movements of the modern machine, was not thoroughly automatic, and several of the important functions had to be performed by the operative, as the following :—

1st. Guiding the faller wire in winding the yarn on the spindle.

2nd. The reversal of the spindles previous to winding, technically termed "backing off."

3rd. The regulation of spindle feed necessary to compensate for the varying diameter of the cop during the building.

If we define the functions of the mule as follows—

1st. Drawing or attenuating the rove,

2nd. Twisting the strands,

3rd. Winding the spun yarn into cops or spools,

we shall see there was yet wanting a more complete mechanism which would dispense with the assistance of the operative in producing any auxiliary movement which was absent.

The first and second of these operations had been brought to some degree of perfection by the efforts of several inventors, and improvements continued for some years; but the perfection of this machine must rest with Richard Roberts, of Manchester, who in 1825, after being approached by several influential persons, consented to attempt something which would satisfy the requirements, and about 1830 we find that the genius of Roberts had asserted itself by producing a machine (Fig. 5) which was perfectly automatic in all the requisite movements, and by this innovation the operative was elevated from the position of a machine part to that of a supervisor.

The most important piece of mechanism in connection with Roberts' mule was the adoption of the quadrant arm—seen on the left of the illustration — together with a screw and nut, which imparted the differential motion to the spindle during the winding. This motion has been further improved by Messrs. Platt, of Oldham, by the introduction of a screw (Fig. 6) of varying pitch engaging with a swivel *B*, the object of which is to secure a more effective grip of the nut on the differential screw than is afforded by the swivel in the ordinary arrangement of quadrant nuts when used with variable quadrant screws.

A section of the quadrant arm with the nut, screw and round-shank swivel is shown in this figure, and may be described as follows :—

The grooves in the nut which receive the threads of the screw are cut to a diameter which coincides with the larger diameter of the screw, the swivel *B* controlling one portion of the screw whilst the nut is used for the other.

It is claimed for this improvement that the swivel acted on one thread only, and that after the cop had reached the full diameter the swivel remained for a long time acting on the same part of the screw, with a tendency to destroy the screw thread.

It may be explained that the motion of this piece of Roberts's most ingenious mechanism is used for the purpose of giving the required form to the cop during the building, and the introduction

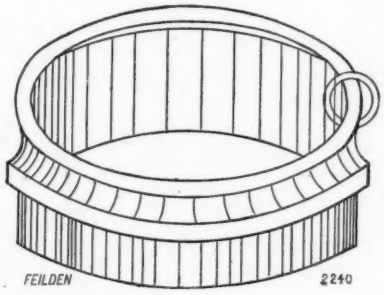


FIG. 8.—RING SPINNING; THE RING.

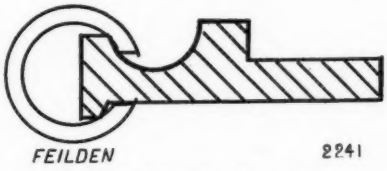


FIG. 9.—RING SPINNING; THE TRAVELLER.

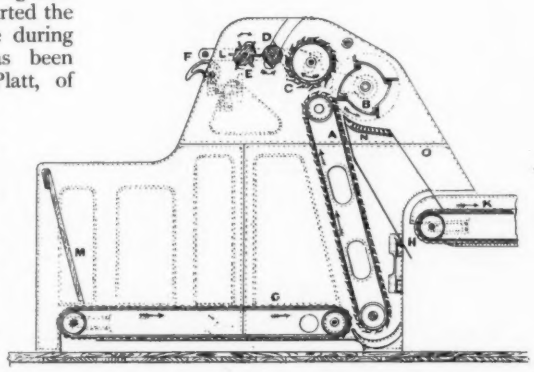


FIG. 10.—FEED FOR SCUTCHERS.

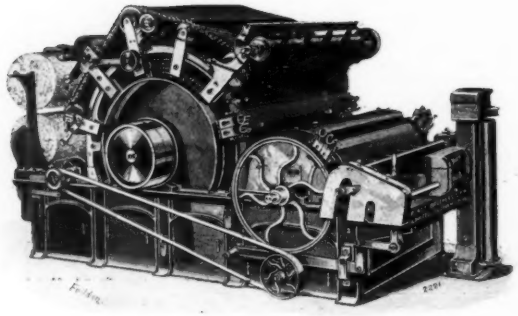


FIG. 11.—MODERN CARDING ENGINE.

of a differential screw within the quadrant arm has practically relieved the minder and modified the responsibility of producing a symmetrical cop, which, with a screw of uniform pitch necessitated a slower or more rapid rotation of the handle as determined by the judgment of the operative.

We must not forget, however, that the *whole* of the mechanical motions as designed by Roberts are existing and embodied in the modern mule.

It therefore speaks volumes for the inventive ability and conception of mechanical ideas possessed by the individual who evolved this paragon of textile machinery.

We may briefly summarize the difference between the Crompton and the modern mule, with all its latest improvements as shown at Fig. 7.

A.—It is thoroughly automatic in all its actions.

B.—Superior mechanical construction.

C.—Multiplication of spindles.

D.—Increased speed with greater production, and a consequent reduction in the cost of labour.

In reverting to Arkwright's water-frame, Fig. 2, it must be admitted that the mechanism was simple but the capacity was limited, inasmuch, as only coarse counts could be spun owing to the extreme tension placed upon the weft, as in the process of winding the bobbin had to be pulled round, which would have broken the threads of the finer counts. With some modification it finally developed into the throstle frame, which carried flyers on the spindles, and this in turn was superseded some 20 years ago by the introduction of ring spinning, which had been in operation in America for some length of time. This process was brought into prominence by the late Mr. Samuel Brooks of Manchester.

Two of the principal features in connection with this method are the ring, Fig. 8, whence it derives its name, and the traveller, Fig. 9. The spindle and bobbin pass through the ring, and the travellers are sprung on the ring as shown in section. These small **C**-shaped pieces are so light that they are dragged round the periphery of the ring by the tension of the yarn during winding, with the result that they impart a twist the same as the flyer of the throstle, but as the strain on the yarn is considerably reduced much finer counts can be spun. These travellers are graded in weight according to the counts to be spun, and the coarser the yarn the heavier the traveller. This method of spinning is generally used for warp and twist yarns.

The difficulty of spinning a cop upon the bare spindle has not yet been satisfactorily accomplished, and remains a problem still awaiting a solution.

Though so much has been done to perfect the spinning machinery, it is almost eclipsed by the improvements made in the machines for use in the preparatory stages of textile manufacture.

For the cleaning of the cotton we have the opener and scutcher, the latter the invention of a Mr. Snodgrass, of Glasgow, in 1797, and introduced into Manchester about 1808.

To both of these machines a considerable number of additions and amendments have been made, notably by Crighton of Manchester, Lord of Todmorden, and Platt Bros. of Oldham. Among the most important of these may be quoted the facilities for adjusting the "stripping rail"

and the automatic hopper-feeding arrangements as shown in section at Fig. 10, which provides a regular supply of material to the machine.

Chief among the preparatory machines stands the modern carding engine, Fig. 11, a triumph of correctness and accuracy, as it must necessarily be after the many improvements, some of which are more pronounced than others, yet all have helped to raise it to its almost perfect state.

A short reference will suffice to mention some of these, and a comparison of the modern card with the early one of Paul's and the intermediate type, Fig. 12, will show how the building up has been accomplished.

Paul's machine consisted of a cylinder covered with cards or points with intervening spaces, the concave bracket on the underside, as shown, being similarly provided with points. This part of the machine was capable of being raised to a convenient height by means of a lever, so that the adjustment could be made in proportion to the amount of raw cotton fixed on the cylinder, and which was carried between the needles or spikes of the cylinder and the concave fixing underneath.

The cotton was then removed by means of a needle-stick, a staff about a foot long provided with a number of points and used in a similar way to a comb.

The next improvement was the bridging of the cylinder by placing the concave fixing *over* instead of *under* the cylinder, the primary step toward the modern card. This was followed by the introduction of an endless band, which formed the carded cotton into a continuous roll, ready for the spinning machine.

Numerous improvements took place from time to time, until the carded cotton was stripped from the cylinder by a comb, and, passing through a bell-mouthed tube, was delivered into a vertical can in a coiled form, produced by the can being made to revolve on its axis. As the cans were filled they were carried away for the next operation of winding.

The next and important invention was the revolving flat card, which is now almost exclusively used. This was by Evan Leigh, of Manchester; since then other important additions have been made, notably the receding comb, by Messrs. Platt Bros., shown at Fig. 13.

So much has been done to develop the spinning section that it may be said without hesitation to have practically made the cotton industry, for it not only added an impetus to the higher branches, such as weaving, but to every component part of textile manufacture.

The progress of weaving comes next in order, and without doubt in importance, but the evolution of the loom seems to have been more gradual, and the period occupied by its development represents many decades anterior to the carding machine of Paul or the spinning jenny of Hargreaves.

As far back as 1678 we have the genesis of the modern power-loom described in

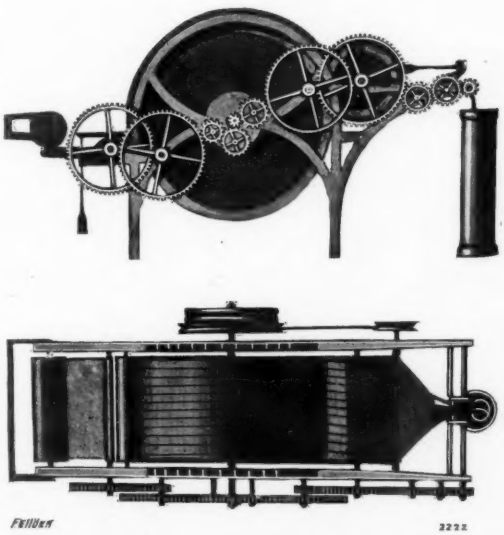


FIG. 12.—EARLY CARDING ENGINE.

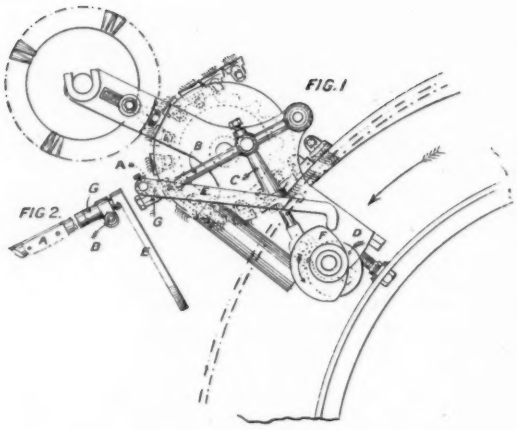


FIG. 13.—RECEDING COMB.

the Transactions of the Royal Society as "a new engine to make linen cloth without the aid of an artificer." Then follows a description of the attributes possessed by the machine, and if they are to be taken as correct it attained nearly all the advantages of the modern loom. Perhaps, on account of the mechanism being crude, or the antagonistic spirit shown towards innovations of this kind, it met with no support.

The next effort was that of M. Vauconson, who, in 1765, invented a swivel-loom, and a number of them were placed in a factory erected by a Mr. Gartside in Manchester, but they produced no exceptional results, as it required the attention of one man to each loom.

Some two years after, the Rev. Dr. Cartwright, of Kent, conceived the idea of a power loom, engendered by his inspection of an automaton chess player, and although destitute of mechanical knowledge, he, after some considerable thought, invented a machine which gave the necessary motions, but was deficient in the smoothness of action which characterised the hand-looms he afterwards examined, as the machine was either so cumbersome, or there was so much friction, that it took a couple of powerful men to work it.

Success attended his perseverance, as in 1809 he received a Parliamentary grant of £10,000 for his ingenious inventions. Some years previous to this date, Dr. Cartwright commenced manufacturing with his looms at Doncaster, but after repeated trials they were abandoned as a financial failure.

Another attempt was made with these looms in a factory at Knott Mill, Manchester, by Messrs. Grimshaw, a cotton-spinning firm of Gorton, who attempted several improvements, but the burning down of the mill put an end to the experiment.

Several individuals now stepped into the breach, and a mill at Glasgow was fitted up by a Mr. Monteith with 200 looms, but several years elapsed before it was made to pay. This was consequent upon the loss of time occupied in dressing or sizing the warp as it unrolled from the beam, this operation requiring the attention of one man to each loom, and therefore no saving was effected. A further drawback was the stoppage of the loom at frequent intervals to allow the warp to be dressed.

The sizing of the warp *before* it was placed in the loom solved the problem, and the invention of the sizing or dressing machine is ascribed to a Mr. Radcliffe, of Stockport, in 1802. Radcliffe, in conjunction with one of his workmen, continued to experiment and improve upon these machines, which he considered would be the principal ones and of the utmost importance in retaining the cotton industry, which, by the exportation of yarn, he thought we were losing.

Further developments in the loom were made by Horrocks, of Stockport, in 1813; and about this time there were 2,400 power-looms at work, but many of these shared the fate of their predecessors in spinning machinery; they were broken by the hand-loom weavers, who recognised in the power-loom the cause of the prevailing distress, which was rightly attributable to something else.

In face of the opposition, manufacturing spinners began to realise its importance as a productive machine, and we find them combining the business of spinning with that of weaving, and from 1833 onwards very few mills were erected for spinning without provision being made for weaving also.

From the latter date we can now proceed to enumerate, seriatim, *some* of the innumerable improvements made in this particular machine.

Commencing with the healds, the earlier forms were in many instances imperfect, straining and pulling the warp in its passage through them. This has been obviated by the superior methods of making the heald twine and varnishing it so as to ensure smoothness in both operations. Wire healds and both metallic and glass eyes have been introduced to assist in the construction of composite healds, and all used with varying success; also woven healds by Cross & Brownhill in 1877.

Dividing or "shedding" the warp is an operation which, to accomplish satisfactorily, has been productive of many improvements in the form of cams or tappets and chains engaging with toothed wheels.

These several forms of mechanism have been devised by Woodcroft in 1838, Clarke in 1840, Knowles in 1849, and afterwards Nuttall.

The first-named of these motions was made up with sectors of a circle, on each of which projections were cast corresponding to the required rise and fall. By dividing the circle into sectors, each one could be placed in a relative position to any other, and so vary the combination that any pattern could be formed which had a number of picks that were a multiple of the number of sectional divisions.

The mechanism for conducting the shuttle through the weft has also been considerably improved upon.

Kay, of Bury, in 1738, introduced his "fly shuttle," but it was not taken up in the spirit that it should have been until some years after.

The modern loom, Fig. 14, is provided with an arrangement very similar to Kay's, but there is still room for some improvement in this particular.

The introduction of a "check strap" by Crook, of Eccles, in 1845, to prevent the rebound of the shuttle, is still in use, but with some modifications.

The damage to the warp consequent upon the shuttle becoming jammed has resulted in several devices for its protection.

About 1834, an arrangement for stopping the loom by operating the driving strap bar was in use, but was improved upon by Bullough, of Accrington, in 1842, and since then by several others in the minor points of detail.

In consequence of the danger to operatives from the flying out of the shuttles, numerous protective designs have been made and fitted, and amongst them may be mentioned both automatic and semi-automatic guards, which act as a

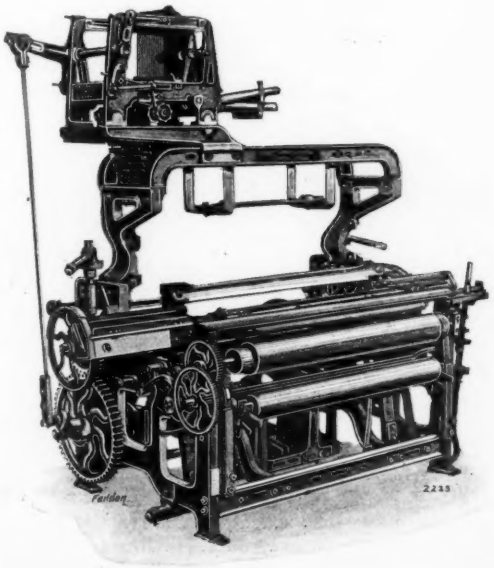


FIG. 14.—MODERN LOOM.

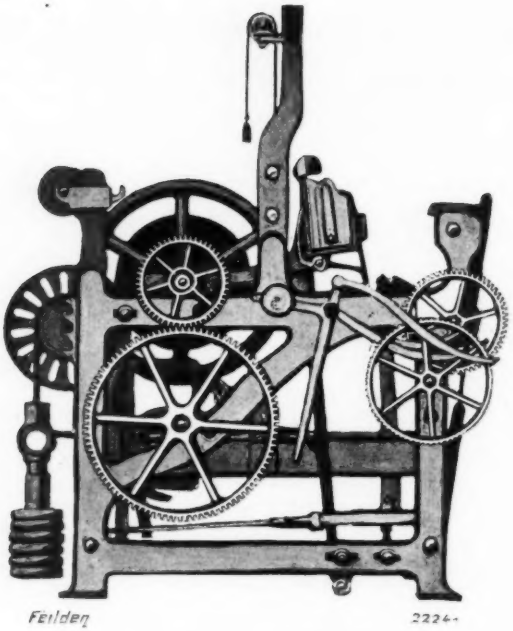


FIG. 15.—POWER LOOM, ABOUT 1833. END VIEW.

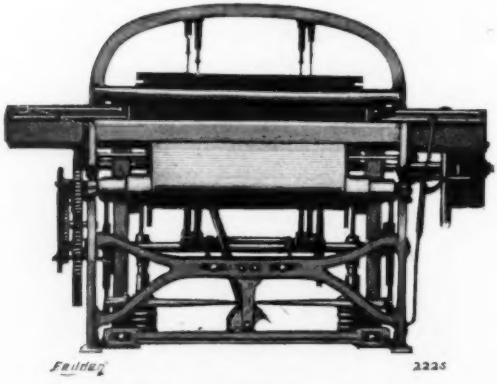


FIG. 16.—FRONT ELEVATION OF THE ABOVE LOOM.

preventive to some extent, but are not yet absolutely perfect; most of them will admit of simplification so as to minimise the labour when changing shuttles.

Among the semi-automatic guards are those of Messrs. Hall & Sons, of Bury, Marriott's patent, and Hamblett & Clifton's.

Entirely automatic guards have also received considerable attention, but as yet have not been a success, the lightness of the mechanism excluding the rigidity necessary to withstand the vibration of the loom.

A considerable amount of attention has been given to several motions for stopping the loom in the absence of weft, and the pioneer of the power loom, Dr. Cartwright, realised its importance, but did not succeed in bringing it to any degree of perfection.

It was not until the invention of the "fork and grid," ascribed to Gilroy, in 1831, that anything definite was accomplished.

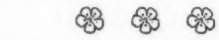
Three years afterwards it was patented, to be improved upon by Kenworthy and Bullough in 1841, further improved by the last-named a year after, leaving it very much as we find it to-day, with a precision of action that leaves little to be desired.

The illimitable number of inventions for brakes, box motions, temples, etc., is almost beyond description, and though we have reviewed at considerable length the varying phases of the textile industry and its machinery, it is scarcely necessary to say in conclusion that only the salient points have been taken.

W. H. Wilson.

Physical Science in the Nineteenth Century.

By GUSTAVE GLASER, Ph.D.



IN no branch of human knowledge has there been a greater advance during the century just completed than in what is known as physical science, and its applications, and to this almost exclusively are due the striking transformations in the general condition of life which are the distinguishing feature of this period, and the sign by which it will be known in history. If we try to find a formula characterising the nature of the scientific achievements of mankind during the last 100 years, we might say that the tendency has been toward simplification, concentration, and unification. The connection established between physical and chemical process, the magneto - electric theory of light, the hypothesis of the conservation of energy, to mention a few of the landmarks at random, clearly illustrate this tendency as far as theory is concerned; and as regards the practical applications, a moment's reflection shows that the vast majority of them have had for their object the breaking down of the barriers of space, and bringing closer together the distant portions of the globe. By the construction of railways and steamships distant countries can be reached in less than a tenth of the time that was necessary in previous centuries. The telegraph has rendered possible an almost instantaneous communication between the various parts of the globe, and the telephone has given wings to the human voice that carry it over hundreds of miles, and ultimately will carry it from one part of the earth to the other, with a velocity equal to that of the telegraphic message. Even the gigantic distances of inter-stellar space no longer offer insurmountable impediments to man's curiosity, and thirst for knowledge. The spectroscope permits us to study the material constitution of suns that are removed from our earth by billions of miles, and the photograph reveals to our eye numberless stars that it cannot see even with the aid of the most perfect telescope so far constructed. Action transferred to a great distance and instantaneous transference of energy by the aid of what for want of a better name we call aether-waves, is a problem solved already for limited areas of space, and all signs seem to indicate an extension of this power to such a degree that thousands of miles will offer no greater obstacle than tens offer at the present moment. All this will gradually draw nearer to each other the various nations and races of the world, and permit them to become better acquainted with each other. Thus, with increasing knowledge of this kind, it is to be hoped prejudices will disappear, sympathy will be awakened and grow, and, instead of waging war against each other, the nations of the earth will co-operate in the work of civilisation and progress that is to secure to man improved conditions in which, being able to supply his animal wants with the minimum expenditure of effort, he will have time to devote the bulk of his activity to higher aims. Much has been done already in this direction during the century just completed, and more, no doubt, will be done in that whose birth we have been witnessing; but let us remember that what has been done so far, is due, above all, to the great strides made during the last 100 years in the knowledge of theoretical and practical physical science.

We often hear the remark that the Nineteenth Century has been the age of electricity. Great, however, as has been the progress of our knowledge of electricity during that period, and numerous

and important as have been its applications for practical purposes, the development of our research into this interesting form of energy cannot fairly be confined in the Procrustean bed of a hundred years. Electricity as a science had its beginning more than three hundred years ago, and owes its existence to the man who selected its name, *i.e.*, to Dr. Gilbert, of Colchester (1540—1603), who has justly been called "the father of experimental philosophy." In fact, after the publication of his famous treatise on the magnet,* in which he describes his careful experiments referring to the interaction of magnets, inquiring into what we now call their fields of force, and points out the difference between magnetic and electric influence, drawing also attention to the effect of the state of the atmosphere upon electricity, no essential progress in our knowledge of electric energy was made until the time of Faraday. Still, the study of electricity was not suspended. Boyle (1627—1691) added several new facts. Otto von Guericke (1602—1686), exciting a sulphur globe by friction, discovered that light and sound accompany the phenomena of electric excitation; that a light body, when once attracted by an electrified body, is repelled by it, and not again attracted until after having been touched by some other body. He also found that light bodies suspended within the field of influence of an excited electric, act as if they themselves had been excited. Sir Isaac Newton (1643—1727) was, it seems, the first† to repeat O. von Guericke's experiments by using a glass instead of a sulphur globe. Francis Hawksbee, in 1709, published his *Physico-Mechanical Experiments*, in which he described various interesting experiments regarding the luminous phenomena accompanying electric excitation and the attractions of electrified bodies. To *Stephen Gray* (1696—1736) we owe the important knowledge that there are bodies which have the power of conveying, or, as we call it at present, *conducting* electricity from one body to another, while other bodies lack this power. Together with his friend Wheeler, he succeeded in conducting electricity from a piece of rubbed glass to a distance of 886 ft. over a pack-thread suspended by silk loops. M. Dufay, of the French Academy of Sciences, confirmed Gray's experiments, and succeeded in enlarging the distance over which electricity can be conducted by wetting the pack-thread and supporting it upon glass tubes instead of suspending it by silk loops. What is more important, however, he was the discoverer of the fact that there are two different kinds of electricity, and gave the name of *vitreous* electricity to that which is produced by exciting glass, rock crystal, hair of animals, etc., and the name of *resinous* to that which is produced by exciting resinous bodies, such as amber, copal, gum-lac, silk, paper, and various other substances. Bodies with the same kind of electricity, he found, will repel each other, while those with opposite kinds will attract each other. By that time the philosophers of Germany and Holland began to be interested in the mysterious power, and Boze of Wittenberg, Winkler of Leipzic, Ludolph of Berlin, and others added to our experimental knowledge of electricity obtained by excitation. In the year 1745, or about that time, partly through accident, the so-called Leyden jar was discovered by Professor Muschenbroeck, of Leyden; there are, however, also other claimants for the honour. Knowing that excited electrics soon lose their electricity in the open air, especially when the latter is charged with moisture, Professor Muschenbroeck wished to see whether they would retain it if surrounded by a non-conductor. For this purpose he electrified some water contained in a glass bottle. It happened, however, on that occasion that his assistant who was holding the bottle, while trying, after connection had been established between the water and the prime-mover, to disengage the communicating wire, suddenly received a shock, and thus revealed the nature of the Leyden jar. It was improved soon afterwards by Sir William Watson (1715—1807), who, in connection with several members of the Royal Society, utilised it

* *De Magnete, Magneticisque Corporibus, et de Magno Magnete Tellure*, London, 1600.
† *Optics*, query 8th.

for a series of very interesting experiments with the object of ascertaining the best means of conducting electricity over long distances. These experiments were afterwards repeated in order to find out the absolute velocity of electricity, and it was found that transmission over a wire of 12,276 ft. was instantaneous. To the same scientist also belongs the honour of having first formed the hypothesis of positive and negative electricity. Passing over a number of experimenters who added more or less important facts to those so far known —as, for instance, that electricity is communicated to homogeneous bodies in proportion to their surfaces only; that, however, it passes through the substance and not only along the surface of a conducting wire; that the growth of plants is hastened by electricity, etc., all of which have been confirmed in more recent times —Benjamin Franklin's name must not be omitted, since his researches added considerably to our knowledge of electricity, both theoretical and practical. Besides, he did more than any of his predecessors in popularising this knowledge, since, on account of their lucidity and attractive style, his writings, especially his work entitled *Experiments and Observations on Electricity made at Philadelphia* 1751—54, and his *Letters on Electricity*, found a wide circulation. Amongst his most important discoveries may be mentioned the truth that electricity is not generated by friction, but merely collected and concentrated from other bodies through which it is diffused, and the fact that in a Leyden jar the inner and outer coatings possess opposite kinds of electricity, while in charging the jar exactly as much electricity is added on one side as is taken away on the other side, the discharge restoring the equilibrium. A discovery of more important consequences was that which convinced him that electricity is abundantly discharged by sharp points, and also easily gathered by such points from electrified bodies; for this led him to the famous experiments in which he collected atmospheric electricity from the clouds by kites furnished with a pointed wire. By these experiments he proved the perfect identity, long suspected, between lightning and the electric sparks obtained during his own experiments and those of his predecessors. He, moreover, found a practical application of this discovery in inventing the lightning-rod. Among experimenters contemporary with Franklin must be mentioned John Canton (1715—72), who discovered that opposite kinds of electricity can, under certain circumstances, be produced by friction in the same electric, and who also revealed and partly explained the fact of electrification by induction; Beccaria (1716—81), who added to our knowledge of atmospheric electricity; Robert Symner, who, c. 1759, demonstrated that the two kinds of electricity were not independent of each other, as Dufay imagined, and showed that a body when positively electrified does not possess a larger quantity of electricity and when negatively electrified a lesser quantity than in its ordinary state, but that in the former condition a larger portion of its electricity is positive, and in the latter is negative; while in a normal state there is an equilibrium between the two kinds of electricity. Delaval, Wilson, Cigna, Kinnersley, Wilcke, and Priestley, all added slightly to the growing store of knowledge. Somewhat later a new phase of electric phenomena became the subject of experiments, namely, the electrification of various minerals by heat. M. Lemery communicated to the French Academy of Sciences the fact that a mineral found in Ceylon, tourmaline, had the power of attracting light bodies. Aepinus, a distinguished German philosopher, demonstated that a temperature of from 99½ per cent. to 212 per cent. is required to develop in tourmaline its attractive powers, thus laying the foundation of what has been called pyro-electricity. The Abbé Haüy discovered that this crystal, together with other crystals, has two opposite poles, and that the polarity which minerals receive from heat is related to the secondary forms of their crystals. Sir David Brewster made important contributions to pyro-technical knowledge, and Aepinus, abovementioned, established an interesting theory of electricity on the basis of the facts so far known. The electricity of

fishes, also, had begun to attract attention about 1676. The ancients knew that contact with the torpedo had a benumbing influence, but the electrical character of this phenomenon was not firmly established until the year 1773, when Walsh and Ingenhousz, by a series of interesting experiments, proved the fact that the shock of the torpedo is electric. Hunter described the anatomical structure of the organs to which it is due. Humboldt, Gay-Lussac, and Geoffroy continued the experiments, and Cavendish imitated the shock produced by the living animal in an artificial torpedo constructed by him. The latter scientist, moreover, made considerable additions to our knowledge of the conducting power of various substances; but his most important experiments were those in which he foreshadowed the future importance of electro-chemistry. It is true that electricity had been employed before as a chemical agent in oxidising and fusing metals; but it was Cavendish who first used electricity for chemical synthesis, and, after experimenting with various proportions of oxygen and hydrogen and examining the products resulting from the passage of an electric spark through mixtures of these gases, obtained the proportion yielding pure water. (*Phil. Trans.*, 1784—5.) The decomposition of water by the electric spark was accomplished by Paets Van Troostwijk and Deiman, while afterwards the methods of performing the experiment were improved by various English philosophers. Galvani in 1790 accidentally discovered that the contact of metals produced muscular contraction.* Further inquiry in this phenomenon resulted in the construction of the so-called voltaic pile by Volta in the last year of the Eighteenth Century. The discovery of electricity resulting from contact of metals, known as Galvanic or Voltaic electricity, became of far-reaching importance during the subsequent period. We have thus reached in our survey of electrical progress the beginning of the Nineteenth Century. This digression into the scientific achievements of the two preceding centuries, no doubt, has been somewhat lengthy, but it will be pardoned, I hope, by the reader of these pages, as it will serve the purpose of showing that the term of the "Age of Electricity" can hardly be applied with justice to the hundred years just completed, since our knowledge of electricity is of much older date, though it has been of slow growth. Still, the Nineteenth Century has been noteworthy not only for the practical application of this knowledge, but also for many far-reaching additions to it.

One branch of electrical knowledge above all—and, moreover, one which promises to be of vital importance for the solution of the practical problems of the new century—namely, the science of *Electro-Chemistry*, may justly be called a child of the last hundred years. True, as we have seen, its earliest germ is found in the concluding portion of the Eighteenth Century—the arbitrary limits established by chronological systems rarely coincide with the rythmical epochs of scientific eras—but there can be no doubt, that it is the Nineteenth Century which has broken down the barrier so long existing between the experimental sciences of physics and chemistry, by showing their separation to be illegitimate. Electro-chemistry practically originated with the successful synthesis and decomposition of water by the voltaic pile. Cruickshank showed that in decomposing the chlorides of magnesium, sodium and ammonium, the alkali always appears at the negative, and the acid at the positive pole. Berzelius and Hisinger in 1803, decomposed salts and some of their bases by the electrical current, and they believed that oxygen, acid, and oxidised bases appear at the positive pole, alkalies and earths at the negative. Later, however, it was demonstrated that it is the

* Strictly speaking, the fact that the contact of metals produces a physiological effect had been discovered many years before Galvani's experiments by Johann Georg Sulzer (1720—1799), Professor of Mathematics at the "Joachimstahlsche Gymnasium," at Berlin. When putting to his tongue a piece of lead and a piece of silver touching each other at their margins, he perceived a taste resembling, as he said, that of sulphate of iron. In his "Theory of Pleasant and Unpleasant Tastes" (Theorie der angenehmen und unangenehmen Geschmacksempfind unger) he shows, that, although he evidently did not fully realise the phenomenon to be of an electrical nature, he came very near discovering the truth, for he expresses the opinion that the taste is not due to a solution (*i.e.* chemical action) of the metals, but that the contact of the metals probably causes a vibration of their particles, acting upon the nerves of the tongue, and that this causes the taste.

metal, and not the oxide, of which this holds good when salts are decomposed by electrolysis, and that oxides cannot be assumed to exist ready formed in salts. Sir Humphry Davy who began his inquiries into electro-chemistry in 1800, discovered, as the result of electrolytic experiments made in 1806, the existence of the metals of the alkalies and alkaline earths, and, in 1807, expressed the view that "chemical and electrical actions depend upon the same cause, acting in one case on particles and in the other on masses of matter." The theory that matter consists of permanent particles, known as the theory of the atomic constitution of matter had been formulated by John Dalton (1766—1844) who, in the year 1804, had communicated it to Dr. Thomson, who published it in 1807 in the third edition of his *System of Chemistry*. It had been in principle anticipated by W. Higgins of Pembroke College, Oxford, in his book: *A Comparative View of the Phlogistic and Antiphlogistic Theories*, 2nd Edition, 1791, but the first lucid statement of it was Dalton's, who was led to his hypothesis during an inquiry into the nature of marsh gas, or light carburetted hydrogen, and olefiant gas, the results of which appeared to be most easily explained by assuming that matter consists of ultimate particles incapable of further division, *i.e.*, atoms, and possessing definite weights, the ratios of which, taking the atom of hydrogen as a unit, could be indicated by numbers. In this way the definite proportions in which, as his experiments showed, the various elements combine could be accounted for. In the year 1808, Dalton published his theory in a more elaborate form under the title of *New System of Chemical Philosophy*, and in the same year Gay-Lussac announced his discovery of the laws of the combination of gases by volume. In 1811, Avogadro enunciated the theory that equal volume of gases contain an equal number of atoms, a theory corresponding to that of Ampère published in 1814, and leading to the important conclusion that the density of equal volumes of gases represents the relative weight of the atoms contained in them. It had been discovered, however, that some gases do not unite volume for volume, and consequently a distinction was established between *atomic weights* and *equivalents*. Berzelius, for instance, pointed out that two volumes of hydrogen are equivalent to one volume of oxygen if we take the relative weights of equal volumes of the two gases to be those of their atoms.

Continuing his electrical researches, he came to the important conclusion of the identity of various chemical and electrical phenomena, which ultimately suggested to him the idea of founding a complete system of chemistry upon a division of atoms into an electro-positive and an electro-negative group. Thus gradually the way had been prepared for Faraday's quantitative electro-chemical investigations, culminating in the year 1834 in the far-reaching discovery that in decomposing electrolytes by the voltaic current, the result obtained shows the quantity by weight in which elements combine, *i.e.*, the weight of the atoms, fully confirming the correctness of Sir Humphry Davy's hypothesis and placing electro-chemical science, the birth of which marks one of the most important steps of scientific progress in the Nineteenth Century, on a reliable and solid foundation. Electro-chemistry, though still young, has meanwhile developed so rapidly and has added so much to our theoretical knowledge as well as to our industrial progress, that it is more than probable that it will become of paramount importance in the present century, and, judging from the results already achieved —we need only bear in mind the radical revolution in metallurgical processes—we can hardly go wrong in predicting for it a leading position in the scientific progress of the future.

Faraday's merit in establishing a firm basis for electro-chemical experiments and discovering a more intimate connection between physics and chemistry than any of his predecessors, would suffice to render his name prominent among the great thinkers of his century; his fame, however, rests rather in the additions he made to electrical science as such.

In the year 1820 Professor H. C. Oersted, of Copenhagen, had discovered

W. Herschell. H. Cavendish. John Dalton. Jas. Watt. John Rennie. R. Trevithick.

A GROUP OF EARLY SCIENTISTS AND INVENTORS.

—not by accident, but as the result of carefully planned experiments with a direct object in view—the important fact that an electric current passing through a wire deflects the needle of a compass, placed below it, in a definite manner, and thus established the connection, long suspected by scientists, between magnetic and electric phenomena. He, like most of his colleagues in other countries, however, was inclined to believe that electricity is a magnetic phenomenon. Ampère, continuing Oersted's experiments, demonstrated the opposite to be true, and by a series of the most brilliant experiments illustrated his theory of molecular currents, in which the interdependence of electric and magnetive phenomena may, in Professor Chrystal's words, be concisely expressed by the statement that "an electric current in a linear circuit of any form is equivalent in its effect upon magnets, or other circuits, to a magnetic shell bounded by the circuit, whose strength at every point is constant and proportional to the strength of the current."* The discovery of this law, the result of a highly interesting method of mathematical analysis, together with the subsequent elaboration of his theory, have placed Ampère's name in the front rank of the great scientists of modern times. To few others, in fact, does electrical science owe so much as to this lucid and erudite thinker, if we except Faraday, who was equal to him in more than one way. Oerstedt's work was not, at first, fully comprehended by his scientific colleagues, as is shown by a number of abortive experiments undertaken among others by Sir Humphry Davy and Dr. Wollaston. Faraday, however, who in 1821, while writing a historical review of electro-magnetism for the *Annals of Philosophy*, had himself repeated all the important experiments made by his predecessors, continued his research, and succeeded in causing a horizontal wire carrying a current to continuously rotate across the vertical lines of magnetic force, thus laying the basis for the invention of the electro-magnetic machines. Arago in 1820, and Sir Humphry Davy in 1821, discovered, independently, the power of the electric current to magnetise iron. This phenomenon was practically foreshadowed in Ampère's theory, which Wilhelm Weber, in 1833, by the employment of delicate measuring instruments invented by himself, was able fully to confirm, as far as this was possible in experiments with closed circuits. Weber's fame, however, as far as electricity is concerned, rests chiefly upon his highly original but rather complicated hypothesis connecting electro-dynamical and electro-statical phenomena, which has been the subject of much criticism, and of which more will be said below.

Meanwhile another phase of electricity had been made known by Seebeck, who, in 1822, discovered that when two different metals are connected in circuit, and if the junctions are not at the same temperature, an electric current will be generated. This became the starting-point of what is known at present as thermo-electricity, a science to which interesting contributions have since been made by Cumming, Peltier, Sir William Thomson (now Lord Kelvin), Tait, Becquerel, Magnus, Mathiesen, Avenarius and others. What has been called the *Magnetism of Rotation*, and afterwards led to highly important practical results, owes its origin to a very noteworthy discovery by Arago, who in 1824 found that a magnetic needle suspended over a rotating copper disc tends to follow the motion. For some time the cause of the phenomenon remained unknown, but it was finally brought to light by Faraday, who in 1831 began the famous experiments, leading to the discovery of *induction*, which more than anything else have added to his renown as a brilliant and acute investigator. This discovery may be summarised as follows: All changes in the number of lines of force passing through a closed circuit are accompanied by the manifestation of an electromotive force tending to create a current in the circuit travelling in such a direction as would produce lines of force passing through the circuit in an opposite direction. This remarkable law, which has found its most important practical application only within the last few years, and represents the essence of a number of very compli-

* "Enc. Brit.," Vol. VIII., p. 10.

cated phenomena, was discovered by Faraday by purely experimental means, and owes elucidation to a train of reasoning and brilliant anticipation of results that have been the admiration of all who have studied the author's original papers dealing with this subject. One of these was published in November, 1831, and another in January, 1832, and yet up to this very day scarcely anything has been added to our knowledge of induction that was not anticipated by the great experimental philospher. To the proclamation of his theory of induction he soon added proof, showing that the induced current had all the qualities of the voltaic current, and that in reality all the various forms of electricity then known—such as statical, dynamical or voltaic, magneto-, thermo- and animal electricity—are identical, as far as experiments can show. A further addition to electrical theory was made by Lenz, whose researches began in 1833, and, together with their results, were described within the two following years. (Pogg. Ann., xxxi., 1834, xxxiv., 1835.) These results comprise what is known as the Law of Lenz, which states, that the direction of the induced current is always such that its electro-magnetic action tends to oppose the motion which produces it. To F. E. Neumann is due credit for having developed the mathematical theory explaining the law experimentally discovered by Lenz, for Neumann is the discoverer of the function known as the "potential" (of one linear current on another or on itself) from which he deduced a theory of induction strictly in agreement with experimental results. (Abh. der Berl. Akad. der Wissenschaft, 1845-47.) In 1846 Weber also had found the mathematical law of induction, deducing it from his above-mentioned elementary law of electrical action and by the use of his accurate instruments had obtained a very exact verification of this law, putting the seal, so to say, upon his own and Neumann's mathematical work. The mathematical calculations received further support from Helmholtz who elaborated a theory of the course of induced currents under certain given conditions, and demonstrated experimentally their correctness, and from Sir William Thomson (now Lord Kelvin), who (Phil. Mag., 1855) mathematically analysed the discharge of a Leyden jar through a linear conductor, expressing the view that this discharge under given conditions will result in a series of decaying oscillations. This prediction was experimentally fulfilled two years later, when Feddersen was able to observe the oscillatory discharge. (Pogg. Ann., cviii., 1857.) Another extension of the mathematical theories is due to Kirchhoff, who explained the application of Weber's law to conductors of three dimensions. The most remarkable contribution, however, to our knowledge of this group of electrical phenomena was made by the late Clerk-Maxwell who, in his work on "Electricity and Magnetism," develops a theory by which the phenomena of the electro-magnetic field are mathematically deduced from purely dynamic principles, with the aid of the fewest possible hypotheses. This theory is developed on the basis of certain equations and comprises an electro-magnetic explanation of the phenomena of light which was afterwards strengthened and expanded by the late Professor Hertz of Bonn, and inaugurates a new epoch of experimental research. True, the equations themselves are not deducible in a very convincing manner from the general laws of mechanics, but the acceptance they found in the scientific world has been vindicated by the results obtained by means of these equations.

We will return presently to Clerk-Maxwell's scientific achievements, but before doing so I shall give a slight outline of the remaining development of electrical knowledge, and will have to refer the reader for fuller information to the historical introduction of Prof. Chrystal's admirable article in the "Encyclopædia Britannica," upon which I have relied in the above for the correct dates, and which contains a very useful summary of the gradual evolution of electrical knowledge.

Among further additions to the theory of electricity not yet alluded to deserves specially to be mentioned the work of Dr. J. S. Ohm, who in 1827 published his

theory of the galvanic circuit ("Die Galvanische Kette mathematisch. bearbeitet"), and, for the first time, supplied accurate definitions of the terms electro-motive force, current, strength and resistance, establishing their relations to each other in the famous law bearing his name. The accuracy of the law was afterwards experimentally verified by Davy, Pouillet, Becquerel, and, above all, by Fechner (1831), who collected a considerable amount of practical evidence. It was most probably suggested to its discoverer by Fourier's splendid work on the "Conduction of Heat"; at all events, the equation for the propagation of electricity derived from this law is virtually identical with Fourier's equation for the propagation of heat. If in Fourier's formulas we substitute in place of the word "temperature" the word "potential," or the expression used by Ohm himself, "electroscopic force" (or tension), and instead of "flux of heat" write current, a formula intended to be a solution of some heat-problem accurately represents the solution of a corresponding electrical problem. Though based on an assumption that at the time remained to be proved, the law itself was found to be accurate whenever tested. The assumption, which is that, "other things being alike, the strength of the current is at each point proportional to the gradient of the potential"—an assumption strictly analogous to that of Fourier regarding the flux of heat—was, at the suggestion of the late Mr. Clerk-Maxwell, tested by means of conclusive experiments made by Prof. Chrystal, and described by him in the report of the British Association for 1876. In these experiments the investigation seems, as the author of the experiments says, "to have been carried to the limit of experimental resources," and the law was found to be true, even when the currents were so powerful as almost to fuse the conducting wire. Since that time there is no physical law more fully trusted than that of Ohm, which ranks with Newton's laws among the accepted foundations of science,

With the publication of Ohm's Law exact measurement became more general in experiments with electricity, and instruments designed to measure current, resistance, and electromotive force began to multiply in number and to increase in accuracy. Among the galvanometers, that devised by Becquerel and that containing the improvements devised by Sir William Thomson, intended for the measurement of resistance, and sufficiently sensitive to indicate the feeble currents of submarine cables, are perhaps the best known, though there have been devised many ingenious and effective instruments excellently adapted for the purpose for which they are constructed.

The practical utilisation of the electric current for telegraphy gave a great impulse to inquiries into the strength of electric resistance. First in this line ranks the work of Wheatstone whose invention of the rheostat belongs to this period. This instrument was later superseded by the resistance-box originally introduced by Siemens. Much ingenuity has been shown also in measuring the electromotive force and the internal resistance of batteries—the lineal decendants of Volta's "crown of cups," which was the first apparatus constructed for producing the form of electricity named after him. The measurement of the electro-motive force of an open battery and of the internal resistance of a battery when traversed by a feeble current, may be satisfactorily accomplished by various methods. Considerable difficulty, however, is experienced in ascertaining the electro-motive force and internal resistance of batteries working with strong currents, since the electro-motive force of a battery depends upon the current it is sending, which interferes considerably and makes it difficult to obtain accurate results. Still Paalzow, Beetz (Wiedmann, I, § 181) and Siemens (Poggendorff's Annalen, 1874) were remarkably successful in trying to solve this problem. Further light was thrown upon the theory of the Voltaic battery during the progress made in the study of electrolysis, notably by Levy and by Beetz, who, in the electro-motive force of polarisation, discovered the true cause of the inconstancy and rapid deterioration of batteries. The various problems connected with galvanic electricity

have been carefully described in Wiedemann's work on Galvanism. The theory of the electric action derived from batteries formed the subject of a heated controversy for many years between those, on the one hand, who, like Volta, maintained that the current is due to the electro-motive force of contact between the dissimilar metals in the circuit, and those, on the other hand, who attributed the appearance of the current to the chemical affinity between the metal and the liquid, denying altogether in some cases the existence of any contact force. We shall return to the theory of the voltaic battery once more after having passed in review the progress in other branches of physical science, notably the discovery of the conservation of energy and the modern theory of dynamics, for without these and the aid of the hypothesis of electro-statics, with a few remarks on which I shall conclude this summary of the evolution of electrical science, a plausible solution of the problem of voltaic electricity could not have been discovered.

In the field of electro-static electricity, again, it was Faraday—whose merits in other fields of electric science have been already pointed out—who discovered some of the most essential facts. Of special interest are the results of his experiments in connection with an inquiry into the phenomena of electro-static induction, for it was during these experiments that the idea occurred to him to investigate the part played by the medium interposed between electrified bodies, which led to discoveries that rendered untenable the theory, accepted by many until then, of direct and immediate action at a distance This theory, one should imagine, could not possibly be accepted by logical thinkers. Yet it is true that in the preface to the second edition of Newton's "Principia" occurs the statement that gravitation is a *causa simplicissima*, which cannot be explained by mechanical laws—a statement that certainly implies an assumption of action at a distance. The preface, however, was written by Cotes, a young friend of Newton, and we cannot hold the latter strictly responsible for it, although his views regarding the laws of gravity underwent many changes during his long life. Against this statement in the preface, moreover, we have Newton's own words in a letter to Bentley, in which he treats with such contempt the assumption of immediate action at a distance that we cannot justly assume that he ever approved of it.

His works and his letters show that, like Huygens, he held the view that there existed some kind of ethereal medium diffused over the universe, and that he was among the first to suggest that this medium might supply the mechanism of transferring material action to a distance. In "Optical Queries" he points out that if the pressure of the medium is less near dense bodies than at a great distance from them, dense bodies will be attracted to each other, and we need merely assume that the diminution of pressure is inversely as the distance from the dense body to obtain the law of gravitation. With regard to the character of this medium, Newton gives no definite opinion, and in a letter to Bentley of the year 1693 he says, "But whether their agent be material or immaterial, I have left to the consideration of my readers." A very strange interpretation has been given by Prof. Zöllner to the doubt expressed here by Newton regarding the immateriality of the mediating agency, and to his above-quoted remark that it is to him an inconceivable absurdity that any man should believe that a material body can act upon another at a distance without the mediation of anything else. Zöllner assumes that Newton by this implied that it would be quite conceivable to him that an "immaterial" living being might act without mediation upon another body at a distance. He thus insinuates that Newton would have approved of his own credulous attitude towards spiritism and telepathy. Almost equally strange it is that, especially on the Continent, the theory of action at a distance was accepted by so many persons. In fact, not before Faraday had shown that the transmission of electric and magnetic forces is accompanied by phenomena occurring in every part of the intervening medium began the æther theory to be taken seriously. After Clerk-

Maxwell's publication of his treatise on electricity and magnetism, however, abovementioned, and Hertz's famous experiments confirming Maxwell's calculations, it was eagerly accepted by all progressive thinkers.

Faraday, during the experiments above mentioned, had discovered that intervening substances varied in their capacity of transferring electrical action from one electrified body to another electrified body. This capacity he called "specific inductive capacity," and his measurements showed to him that many substances have it in a much greater degree than air. Poisson and Gauss during their own famous researches had devised a method by which it can be shown that all phenomena of static electricity can be reduced to mere attractions and repulsions exerted at a distance by particles of an imponderable medium. Sir William Thomson, in 1846, on the basis of an entirely different assumption, and starting from other analogies, had mathematically obtained precisely the same results. The difference between the inductive capacities of various substances was verified among others by Matteucci and Siemens, and the latter improved the method of measuring these capacities. Faraday had extended his inquiries also into the inductive capacities of gases, but failing to discover differences, had assumed that their capacity was equal. It is the merit of Boltzmann to have both detected and measured the inductive differences of gases. Another addition to our knowledge of electrostatics was made by Sir W. Snow Harris, who published the interesting results of experiments made by him with the object of ascertaining the influence of the surrounding medium upon the electric spark. Faraday repeated these experiments and added a number of new facts. Sir William Thomson measured the electromotive force required to produce a spark in air, and found it to be proportionally smaller for long than for short distances. As one of the results of inquiries concerning the effect of surrounding medium on a spark, the luminous phenomena in vacuum-tubes were discovered, which since the results obtained by Prof. Röntgen, have become of special interest. A great deal of information on static electricity is contained in the work of Riess on "Reibungselektricität"; and the "Essay on the Application of Mathematical Analysis to the Theories of Electricity and Magnetism," by George Green, is a treasury of data, that has been of great value to all later investigators, since Green's work furnishes a reliable basis for a satisfactory mathematical theory of electro-statics. Invaluable assistance was given to those engaged in experimental research by Sir William Thomson's design of instruments of precision—chief among them his quadrant and his absolute electrometers; and by his excellent suggestions of methods likely to lead to important results. Among his direct contributions to theory, that of electric images and the method of electric invasion based upon it mark an important step in the progress of mathematical research. To this must be added his demonstration of the distribution of electricity on a spherical bowl, which is of great interest in connection with the theory of partially closed conductors, and by its ingenuity created the highest surprise among all engaged in electric research.

A mere glance at the outline of progress in our knowledge of electrical phenomena, above given, will show that almost every step in the direction of advance has been the result of painstaking and diligent research, and of a strong desire to obtain the most accurate results. Very little was the result of accident, nothing almost was the outcome of mere guesswork. This conscientious research, carefully guided by experiments and a constant appeal to objective reality, and the results obtained are directly attributable to the philosophic tendency prevailing in the Nineteenth Century; they are the fruits of the teachings of Kant, who had convinced most of those who studied his works of the truth that all mental efforts expended in attempts to find a reply to ultimate questions are vain, and that the only knowledge within reach of the human mind is to be looked for in the data of experience, classified and combined in agreement with the Laws of Thought or, as some call them, Laws of Nature, that

rule our conscious universe. Thus the objective world so long looked down upon and treated as hardly worth noticing by the wise, and as something to be shunned by the pious, re-entered into its legitimate rights and has within the last hundred years been treated with the respect that it deserves—as one of the given data of consciousness. The Nineteenth Century has been a period of inductive philosophy, an era of careful research and logical reasoning. It has not looked very kindly upon poetry and other works of imagination; but, though somewhat stern and matter-of-fact in its pursuits, it has not been unkind, on the whole, to those who have lived in it, and has left a rich inheritance of useful scientific facts, both applied and applicable, to later generations. Among the applications of scientific knowledge during the last hundred years none are more striking than those resulting from the study of electricity, and—excepting, perhaps, the use of steam—none have aided more in creating the modern conditions of life than the invention of the electric telegraph, the telephone, electric light, and electric transmission of force. It is beyond the scope of this contribution to make more than a passing allusion to the applications of electricity, as they are fully discussed in another article in this issue of FEILDEN'S MAGAZINE; but it was owing to their paramount importance that the writer of these pages found himself compelled to devote so large a portion of the space allotted to him for an outline of the progress of physical science during the past century to the science of electricity. Far-reaching, however, as our progress in the knowledge of electrical phenomena has been, it will in its ultimate effects appear insignificant compared with the great revolution in our views regarding the theory of dynamics, which is the fundamental portion of the physical sciences. This revolution began only toward the middle of the century, but has since practically conquered intellectual Europe, and promises to become the basis of an insight into the laws of the material world, far greater than that possessed by any person in the present generation.

Its origin was the discovery of the famous law, the Conservation of Energy, which, expressed in the form given to it by the late Prof. Clerk-Maxwell, reads as follows:—"*The total energy of any body or system of bodies is a quantity which can neither be increased nor diminished by any mutual action of those bodies, though it may be transformed into any one of the forms of which energy is susceptible.*" A dim outline of this truth may perhaps have been present in the mind of the great thinkers of former ages, since, when once expressed, it appears so plausible as apparently to require no confirmation; which means that it is in perfect harmony with the laws of thought, *i.e.*, the laws of nature. Profs. Thomson and Tait in their "Natural Philosophy" try to show that Newton realised the existence of this law, at least so far as mechanics are concerned, although he could not account for what to him appeared to be the loss of the work done against friction. Bacon made a very near guess at the truth; for in the "Novum Organum," after enumerating what he considered to be sources of heat, he remarks: "From these examples, taken collectively as well as singly, the nature whose limit is heat appears to be motion," and elsewhere he attributes heat to a kind of "brisk agitation" of the particles of matter. In the "Philosophical Transactions" for 1798, Count Rumford published the results of a number of highly interesting experiments made in connection with the boring of a cannon, during which, after trying by various means to account for the great amount of heat produced by the action of the boring instrument upon the brass castings he came to the conclusion that it was entirely the result of the friction, and that the supply was inexhaustible. In stating this, he remarks:—

"It is hardly necessary to add, that anything which any insulated body, or system of bodies, can continue to furnish *without limitation*, cannot possibly be a *material substance*; and it appears to me to be extremely difficult, if not quite impossible, to form any distinct idea of anything capable of being excited and communicated in the manner that heat was exerted and communicated in these experiments, except it be *motion*."

At the time of the publication of Count

Rumford's experiments, Sir Humphry Davy demonstrated that two pieces of ice, by rubbing them together in a vacuum, could be melted, notwithstanding that everything surrounding them was at a temperature below the freezing-point.

Although Sir Humphry Davy did not realise that his experiments sufficed to show the dynamical origin of heat, the fact here described, as well as Rumford's experiments, were quite sufficient to overthrow once and for all the theory of the so-called "Calorists," who maintained that heat is a material fluid. Nevertheless it took fifty years ere the scientific world in general realised this fact, "a remarkable instance," Lord Kelvin justly remarks, "of the tremendous efficiency of bad logic in confounding public opinion and obstructing true philosophic thought." It was reserved for Dr. Joule of Manchester to show, by his famous experiments from 1840 to 1849, for the first time—which was not apparent from either Rumford's or Davy's experiments—that the amount of heat generated by friction is not influenced either by the time during which the friction acts, or the distance over which the rubbing bodies travel, or by any other conditions—in fact that it is quite independent of everything except the *amount of energy* expended, to which it is directly proportional It is due therefore to Dr. Joule that we know that heat and energy are of the same nature, and that all the other forms of energy we know can be transformed into an equivalent amount of heat. Mohr, Séguin, and Mayer had, before Joule's experiments were published, come very near in their speculations to the correct interpretation of the phenomena, and Colding, in a paper addressed to the Royal Society of Copenhagen (1843), had clearly illustrated the "principle of the perpetuity of energy," but all of them failed to establish the convincing proofs which were furnished by Dr. Joule during his very carefully planned and accurately performed experiments. His name therefore will ever remain in the front rank of the great scientists of the Nineteenth Century.

The law of the Conservation of Energy has since become the basis on which the harmonious structure of modern physical science has begun to rise. Its discovery gave a new impulse to researches into the interdependence of the various branches of the physical sciences, the complete unification of which will almost certainly be accomplished, since such a unification may almost be called a logical necessity. The sanguine hopes awakened during the middle of last century have not all been fulfilled as yet, but much has been done, and more still will be done in the near future. The establishment of a connection between electricity and magnetism, to which reference has been made in the previous pages, was one of the first steps toward unification. The next was more far-reaching yet, namely, the discovery of the relation between magnetism and light. The pioneer in the researches that led to this discovery, as we have seen, was Faraday, who had at a very early period of his scientific life formed the idea of using a ray of polarised light as a means of investigating the condition of transparent bodies when acted upon by electric and magnetic forces. For many years his experiments remained fruitless; but at last, in 1845, he was completely successful, and established the fact of the magnetic rotation of the plane of polarisation of a ray passing along the magnetic lines of force.

It was upon the basis of these discoveries that Prof. Clerk-Maxwell established his electro-magnetic theory of light, mentioned already in outline, and to which I now return in order to describe its further development and the consequences it had for our modern treatment of some of the most important problems of physical science. Maxwell, like Faraday, keenly realised the unscientific character of an explanation of physical phenomena which is based upon an assumption of action at a distance, and he had been looking from the very beginning of his scientific career for an opportunity of overthrowing this theory. He had read and studied with profound admiration the whole of Faraday's writings and endeavoured to give to Faraday's theories a concise mathematical expression, but it was not until after Sir William Thomson had, in 1846, arrived,

in his own manner, as we have seen, at an explanation of the phenomena of statical electricity in perfect agreement with that of Poisson and Gauss, that Maxwell saw his way to carry out his purpose. It was from Sir William Thomson's paper, published that year, in which he treats the electric force present at any point as analogous to the *flux of heat* from sources distributed in the same manner as the supposed electric particles, that Prof. Clerk-Maxwell developed his famous hypothesis in a manner that at once revealed his great mathematical genius. In his treatise on "Electricity and Magnetism," taking Lagrange's well-known co-ordinate system as a starting-point, he demonstrated how to reduce all electric and magnetic phenomena to stresses and motions of a material medium. Although Maxwell's equations, as mentioned already, to a certain extent rest on assumptions which, as he himself fully realised, require confirmation, his theory has since been found to agree completely with experimental facts. Being subjected to the preliminary but extremely severe test of showing whether the velocity of light *in vacuo* is numerically the same as the ratio of the electro-magnetic and electro-static units, which must be the case if the medium required to explain the phenomena of electricity and magnetism is identical with that required for the explanation of the phenomena of light, it was found that there was a very fair agreement even at the time when these quantities were but approximately known. But the crucial test of the theory of Maxwell was not obtained until, in 1887, Prof. Hertz, of Bonn, discovered that the ethereal radiation of a long wave-length emitted from electric oscillators fully verified Maxwell's calculations. To Hertz belongs the credit of having once for ever established on an experimental basis the connection between the phenomena of light and electricity, and during the last few years of the century many students of the highest ability have been devoting themselves to the exploration of this new field of science thus created, and have added many minor discoveries, thus constantly strengthening and continuing the edifice planned and partly constructed by Faraday, Maxwell, and Hertz. Among the latter Poynting deserves perhaps special mention for his ingenious method of specifying the path of the transmission of energy through the ether, thus connecting the electro-magnetic theory of light with the applications of electro-dynamics. To what practical applications these important discoveries may yet lead in the present century it is difficult to foretell, but we have already achievements to register, such as what is awkwardly called "wireless telegraphy," for instance, which justify the highest hopes.

The Nineteenth Century has witnessed enormous transformation of human conditions in consequence of the invention of the telegraph and, to some extent, of the telephone; the Twentieth Century begins with the prospect of increasing the transmission of power to almost any distance, at enormous tension and without appreciable waste, along lines suspended in the air.

The material conductor which, so far, serves to guide the ether currents will probably sooner or later be abandoned in most cases where it is used at present, and the means of distributing mechanical power from sources where it is easily obtained to places where it is lacking will most likely be considerably increased.

The development of the ether theory has indirectly also resulted in a most important expansion of scientific theories closely connected with it. Researches into the phenomena of vacuum tubes have been revived with remarkable and very gratifying results. In these tubes, where there are great distances intervening between the individual molecules, and where collisions are comparatively rare occurrences, the prevailing conditions are such as to enable us to study with greater care the part played by individual molecules in electric phenomena.

Of Prof. J. J. Thomson's highly important discoveries, including the establishment of the approximate size and velocity of the particles that convey the electric charge across space, mention has already been made in this magazine on another occasion. Others have of late

verified his calculations and followed his lead in their experimental research. The discovery of the Röntgen rays and of electric dissociation by ultra-violet rays of light have added important facts to our knowledge of molecular physics. It would be quite impossible to mention even the names of all those who in recent years have aided the progress of physical science, much less, therefore, to give an outline of their achievements within the limited space of this article; all that is possible is to indicate the general drift of progress and to mark the steps reached up to the present time.

Since the existence of an ether is at present the generally accepted theory, and is the only one that satisfactorily explains the facts so far known, it may be pointed out that there is, nevertheless, no absolute agreement as yet regarding its probable constitution. Helmholtz has demonstrated the peculiar and unique character of rotational motion in a homogeneous incompressible fluid devoid of all viscosity, as represented in vortex motion. Lord Kelvin has familiarised us with the idea of looking upon the ether as a perfect fluid, and upon the atoms of matter as vortex-rings in this fluid. Riemann, instead of vortex-rings, assumes the atoms to be represented by points where the ether is constantly destroyed; and quite recently Professor Larmor has published his view that the atoms are represented by a special kind of torsion in the ether. Also as regards the distribution of matter in space, although there is a fairly general consensus between the representatives of modern science to interpret the structure of the universe in agreement with the laws of dynamics or mechanics, there are differences in so far as some still retain the idea that the molecules are moving along a straight path, being deviated by shock only. The more generally accepted theory is that of Maxwell, according to which the molecules are arranged in a system resembling our articulated systems, thus making the structure dependent upon the laws of pneumatics. This latter theory has been further developed by Prof. Hertz. Whichever of these theories most simply explains the known facts of science is the one that must prevail and continue in existence until new and unexplained additions to our knowledge demand us to look for another explanation. For the time being the theory that sees in the structure of the universe the strains and stresses of mechanics promises to be the most fruitful. So also the hypothesis of the atomic constitution of matter, although in its ultimate interpretation it is as inconceivable as the hypothesis of a continuous universe, has so far been most successful in helping us to classify and arrange the data of experience. The modern chemist has erected on its frail basis a structure of most astounding dimensions, and, which is better, has made this structure a treasure-house, harbouring a wealth of useful knowledge such as the alchemist of former centuries never imagined in his wildest dreams. And yet we know of an atom nothing except certain phenomena which are best explained by assuming them to be the result of its interaction with other atoms that, as Prof. Larmor recently stated, are so far removed from it as to be practically independent systems. Nevertheless, the logical arrangement of physical laws—a metaphysician, no doubt, will smile, and justly so, at the statement of this self-evident fact—permits us to make plausible guesses as to the probable constitution and arrangement of groups of these assumed atoms, though in every case we have to deal with millions or even billions at a time.

True, the discovery of the spectroscope by Fraunhofer, and the researches of Kirchhoff and Bunsen—which are among the greatest scientific achievements of the century—have removed to a considerable extent the obstacles in the way of our obtaining a more thorough knowledge of the molecular constitution of matter. By this method we are, at all events, enabled to inquire into the nature of an individual atom and of the vibrations that are taking place in it. Wonderful have been the results obtained by the great thinkers of the past century with the comparatively slender mechanical means at their disposal—so wonderful that it is not astonishing to find among the more weak-minded investigators

some who, overcome by the greatness of their success, almost relapse into a belief of the semi-divinity of human nature fashionable during the halcyon days of Hegelian philosophy. A good sedative for this emotional delirium ought to be the fact that, as Prof. Clerk-Maxwell so justly points out, a physical atomical theory is not competent even to contemplate the enormous complexity of possibilities and inter-relations that would have to be taken into account to obtain something like a faint idea of a single organic germ, though it presumably contains but a few millions of atoms. Professor Maxwell, however, also expressed the opinion that the properties of such a germ cannot be those of a "purely material" system. Those who treat matter as something self-existing and distinct from mind, not as a necessary assumption for purposes of research only, but in reality, must certainly agree with this view, since the laws of matter, taken in this sense, do not even touch upon the essential phenomena of organic life. Those, on the other hand, who consider physical science as a means of dealing with one phase of the same reality merely, which appears to us in another phase under aspects requiring a very different attitude from that which the scientist must assume in order to construct a complete and self-dependent image of his external universe, will not so readily agree to a limitation of the atomic theory to the interpretation of inorganic nature merely. The atomic theory, apparently derived from the data of experience, forcing upon us the belief in an external universe consisting of separate particles, like the motion of space and time, owes in reality its existence to the laws ruling our consciousness, and rendering the presentation of a continuous universe inconceivable. Of course a discreet universe is equally inconceivable in its ultimate interpretation, yet, provided we bear in mind its merely logical existence, it offers the only satisfactory working hypothesis in our present state of knowledge, and will continue to do so unless consciousness ceases to be what we perceive it to be. This being so, there is no good reason for limiting the subdivision of the objects of thought to merely one class of objects, and, as far as truth is attainable at all, it will facilitate the acquisition of knowledge both of organic and inorganic phenomena. In fact, once that the limits of reason are fully grasped, it seems but fair to try all our mental resources on all possible subjects of research; and a great deal of the progress of the past century must be ascribed to the fact that modern thinkers have ceased to consider ā part of the universe tabood, and have dared to try their intellectual power in the solution of problems that formerly seemed to be unapproachable.

The theories of physical science that have succeeded each other, and grow and expand in true accordance with the laws of evolution, comprising ever wider and wider areas, are being constantly modified so as to cover every new part of human experience. A voluntary limitation of their application is impossible; the human mind will not rest satisfied face to face with unexplained exceptions, and, though conscious of its limits, demands completeness and uniformity as far as these are obtainable. It is owing to this that such theories as are restricted to portions of the field of knowledge only are unhesitatingly rejected—a process by which the number of separate laws is steadily being reduced, and a tendency towards absolute unification—which in no way interferes with an almost illimited sub-division — is everywhere perceptible.

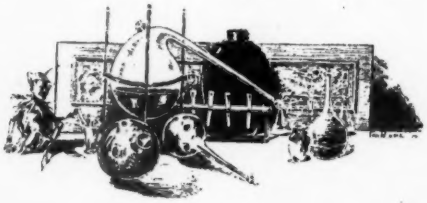
This tendency is well illustrated in the development of the theory of the dynamics of the ether, which could not be reached without sacrificing many ideas that at one time formed the very groundwork of physical science. If we analyse a material system and reduce it to its purest and simplest form, it becomes, as Professor Larmor points out, a "formulation of the relations between the succession of the configurations and states of motion of the system, the assistance of an independent idea of force not being usually required." This, of course, holds good, he adds, of self-contained systems only, when their motion is not dissipated by friction or similar agencies, and when their connections can be directly expressed

by purely geometrical relations between the co-ordinates.

Under these circumstances, of course, Newton's laws lose their paramount importance, and begin to be treated with less reverence than was customary in former times. In fact, the third law has not stood all the tests to which it was subjected by the inquisitive searcher after truth, and the question of its applicability to certain problems has given rise to much controversy in recent times. Thus, for instance, the idea of force as a cause of motion is in conflict with the third law. Fortunately this idea is no longer required, and, in fact, would not fit into the present hypothesis. Looking upon the structure of the universe as a self-contained system, its course is determined in all cases by some innate conditions, on account of which any alteration in any portion of its course however small must produce an increase in the total "action" of the motion. Thus the Law of Least Action, in connection with the principle of the Conservation of Energy, suffice to complete a mechanical theory that is constantly being verified by the facts of our experience. This principle of Least Action remains as the ultimate residue after eliminating what is merely contingent in the principles of the dynamics of material systems. Prof. Hertz gave to this principle the expression of straightness of path, and clearly demonstrated that wherever it applies it gives the most comprehensive formula of purely dynamic action and comprises the complete course of events.

The ultimate test is to find whether its relations can in some way be consolidated into accordance with the principle of Least Action. Whatever may be the objection toward the adoption of a dynamic hypothesis, such as is here described, the very fact that it has found favour with the best-known leaders in the field of exact science such as Helmholtz, Lord Kelvin, Maxwell, and Hertz, is, as Prof. Larmor justly remarks, a strong guarantee that we shall do well to accept it. The principle of Least Action has undeniably been found to be a strong foundation for the fruitful study of electrodynamics and optics from the very beginning. It has not been invalidated by the introduction of the ether theory, and we have good cause for assuming that the progress of the Nineteenth Century will be continued in the present on the same basis, on which we may hope to build up a complete dynamical explanation of radiant vibration, and find a valid formula for the dynamical energy of the molecule which, for the time being at least, is a sufficiently ambitious, though not impossible, aim.

GUSTAVE GLASER.



The Development of Electrical Engineering.

By G. W. De TUNZELMANN, B.Sc., M.Inst.E.E., Etc.

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We have to recognise the existence, in the physical universe, of three entities, which are so far distinct from each other that we cannot by any means at our disposal create or destroy any portion of either one of them; nor can we transform any one of the three into either of the other two.

These are, firstly, Matter, which is the most familiar to us because our muscular sense is directly cognisant of it; secondly, Ether, which fills the whole of known space, which permeates ordinary matter, and is the vehicle of transmission of electro-magnetic waves, including those which produce upon our sense organs the effects known as heat and light; and, thirdly, Energy, which is less directly apprehended by our senses than either of the other two, but which is just as truly existent, and, like Matter, can only be transferred from one portion of space to another by some definite continuous path.

Having recognised these three distinct components of the Physical Universe, we may define the province of Engineering as being the production and utilisation of Energy, using the word production in its primary sense, for we cannot create energy, but can only draw it forth from some already existing source.

Now, Energy may be associated with and carried by either Matter or Ether, but, unless we admit the possibility of action at a distance, it must always be associated with one or the other.

The solution of any engineering problem will consist, in its simplest form, of three distinct steps:—1, the selection of the most convenient available source of energy; 2, its transmission to the place where it is to be utilised; 3, its application to the production of the desired result. The second and third steps will, in general, involve one or more transformations of the original energy into fresh forms.

With the exception, therefore, of some few cases which we have not yet been able to classify, engineers have to deal with energy in two distinct and well-recognised forms, viz., in association with matter as mechanical energy, or in association with ether as electrical energy, so that for practical purposes the province of engineering may be divided into mechanical engineering, which may be defined as that portion of engineering practice, and electrical engineering, which may be defined as that portion of engineering practice which is concerned with the production and utilisation of electrical energy.

Every series of energy changes affecting materially organised beings must at least begin and end with energy in a mechanical form, while electrical energy need not necessarily form a part of it. The distinction, therefore, between the purely mechanical engineer and the electrical engineer is that the former is confined to a portion only of the field open to the latter. In other words, a mechanical engineer need not be an electrical engineer, but an electrical engineer must be a mechanical engineer. So much indeed is electrical engineering concerned with mechanical problems that it is quite possible and not even uncommon for an extensive electrical engineering practice to be carried on by men who have no knowledge whatever of electrical theory. Had it not been, however, for engineers and other scientific men who have made a profound study of electrical theory, the practice of electrical engineering would never have advanced with the giant strides which it has taken during the century which has just come to a close.

Passing over the results achieved by earlier experimenters, Oersted, in 1820, made, by means of a voltaic battery, the fundamentally important discovery of the action of an electric current upon a compass-needle, which led to the development, by Ampère, of his mathematical theory of electro-magnetism, and to other important investigations by Biot, Laplace, and Arago. In the following year, Sir Humphry Davy found that a copper wire carrying a current attracted iron filings, each filing or chain of filings tending to set itself at right angles to the axis of the wire; and it was in this year (1821) that Michael Faraday made his first important scientific discovery, that of electro-magnetic rotations. In spite of Oersted having definitely pointed out that, to use his own words, "the electric conflict acts in a revolving manner" upon the pole of a compass needle, this rotatory action appears to have been lost sight of in the discussions which followed, which were entirely directed to the consideration of attractions and repulsions, with which mathematicians and physicists had been familiar since the time of Newton.

Dr. Wollaston, however, had suggested that when a magnet pole was brought near to a straight line carrying an electric current, there should be a tendency for the conducting wire to turn upon its axis. Neither Wollaston nor Faraday, who followed up his experiments, were able to obtain any indication of such an effect (which, however, has been observed in recent years by Mr. George Gore), but Faraday succeeded in making the wire revolve round the pole, or the pole round the wire.

In 1824 Arago discovered the damping effect of copper on the vibrations of a magnetic needle, and reasoned therefrom that if a flat copper disc were caused to rotate under a suspended metallic needle it should drag it round, which he found to be the case; but though many explanations were attempted, the true reason, the production of induced currents in the copper, was not even guessed at. In the following year, William Sturgeon published his paper describing the electro-magnet which he was the first to construct.

In the year 1827 Ohm published a most important paper in which he showed that the strength of the current between any two points of a conductor is proportional to the electro-motive force between the two points, divided by a certain quantity depending only upon the dimensions, material, and physical conditions of the conductor, which he called its electrical resistance; and for some years after this discovery, electricians continued to follow his example in expressing the resistances of different portions of a circuit in terms of the resistance of a selected portion of it; and it was not until 1837 that Pouillet took the important step of expressing all his measurements of resistance in terms of the resistance of distilled mercury, using as a standard the resistance of a column of mercury of a measured length, contained in a glass tube.

In 1831, a year memorable in the history of electro-magnetism, Faraday constructed the ring of soft iron 6 ins. in external diameter, shown on the right-hand side of Fig. 1, which, together with Fig. 2, are photographs taken by kind permission of the authorities of the Royal Institution, of the apparatus used by Faraday in these world-famed investigations, and are treasured among their most precious relics. Three coils of copper wire, each about 24 ft. long, are wound on this ring, and insulated from each other with twine and calico.

The ends of one of the coils on this ring were connected with a copper wire passing over a compass needle some 3 ft. away from the ring, while the ends of another coil were connected by copper wires to a voltaic battery of ten cells. The needle was observed to be slightly deflected whenever the battery circuit was made or broken, the deflection being only momentary, and the needle coming to rest after a few oscillations. Thus was made the fundamentally important discovery of the mutual induction of electric currents. This was at the end of August. Faraday then set to work to devise and make fresh apparatus, and after a few failures he discovered that currents could be produced in a circuit by moving it

relatively either to a magnet or a circuit carrying a current, and he very soon noticed the effect of iron cores in greatly increasing the induction in every case, the effects being much smaller when coils wound on rods of wood, copper, and other materials were employed. A second pair of coils wound on an iron rod is shown on the left-hand side of Fig. 1. He further made a copper disc rotate between the poles of a compound steel horse-shoe magnet belonging to the Royal Society, and connected the axis and edge of the disc with copper wires through a galvanometer. The galvanometer needle was deflected when forces which would be depicted by iron filings." The existence of these "lines of force" had been demonstrated by Gilbert, by means of iron filings, 200 years before, but it was Faraday who first showed their true significance, and soon after showed that similar but fuller effects could be produced by moving the coils so as to cut the earth's lines of magnetic force. He then repeated his former experiments with the steel magnets and a much more powerful battery, and after getting the same results as before he removed the galvanometer and attached small pencils of charcoal to the ends of the helix

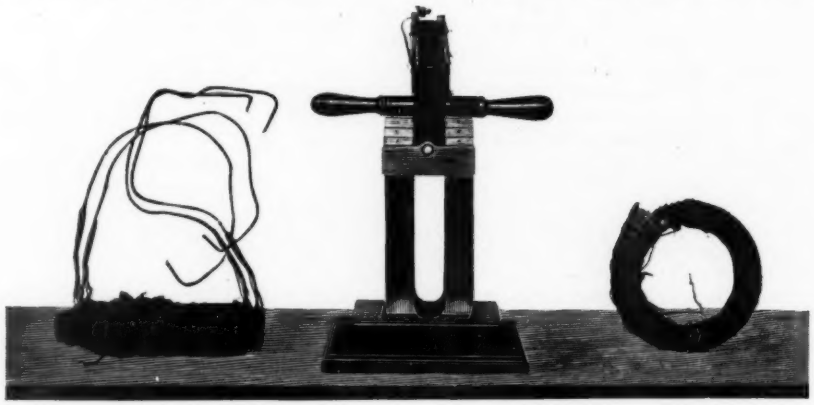


FIG. 1.—TWO OF THE ORIGINAL INDUCTION COILS MADE BY FARADAY. COMPOUND STEEL MAGNET AND COIL BUILT FOR SOME OF HIS LATER EXPERIMENTS. (ROYAL INSTITUTION COLLECTION.)

the disc rotated, showing the existence of a current, and this was the first instance of the continuous production of an electric current by the rotation of a conductor cutting the lines of force of a magnet, which is the principle of the modern dynamo. The experiment was repeated later with the same copper disc and a powerful electro-magnet, both of which are shown in Fig 2. On the 4th of November he found that a copper wire drawn between the poles and conductors produced the same effect. In his description of this experiment, Faraday speaks of the metal cutting the "magnetic curves," saying in a note to his paper, "By magnetic curves I mean lines of magnetic in which the currents were induced, these pencils being allowed to just touch each other. To his great delight he observed a small spark between the charcoal points when the battery circuit was made or broken, which he regarded as an indication that he was really producing an electric current. We may look upon this experiment as the first production, on a minute scale, it is true, of an electric light by induced currents in a transformer, for the two induction coils shown in Fig. 1 are the first examples of closed and open circuit transformers respectively, and it will be interesting to the reader to compare these beginnings of the transformer with the most recent

FIG. 2.—FARADAY'S ORIGINAL COPPER DISC WITH LARGE ELECTRO-MAGNET, BUILT UNDER HIS DIRECTION. (ROYAL INSTITUTION COLLECTION.)

practice on a large scale as exemplified in the latest great Westinghouse transformer, of which a photograph is shown in Fig. 10. Early in 1832 he succeeded in getting a spark from a magnet by means of the central apparatus in Fig. 1, which consisted of a coil of wire wound upon an iron bar, one of the ends of the coil terminating in a small plate on which the other end rested, so that a jerk would open the circuit. The ends of the bar were then placed in contact with the poles of the compound steel magnet, and a spark was seen when the coil was pulled away from the magnet, or suddenly put on to it, as the jerk in each case opened the circuit at the instant of making or breaking the magnetic circuit. The apparatus with which the spark was first obtained was not provided with the wooden handles shown, and was altogether of more primitive construction, as shown by the sketches in his note-book. He then repeated the experiments with a large Siberian lodestone, lent to him by Professor Daniell, of King's College, London, and which forms the central object of Fig. 3, the lodestone being shown in the quaint brass case in which it came from Siberia towards the end of the eighteenth century. Fig. 3, as well as Fig. 4, are from photographs of apparatus now preserved in the Wheatstone Museum at King's College, and which I was allowed to have taken for this article by the kind permission of the College authorities.

During these investigations Faraday had noticed the fact that the effects due to breaking the primary were always greater than those produced on closing it, and he made several attempts to obtain direct evidence of the production of induced currents in the primary circuit itself. He was not, however, successful in getting any further than the difference in the effects of making and breaking it respectively.

While Faraday was making these discoveries in England, Joseph Henry, in America, was pursuing a very similar line of investigation by means of spirals of flat copper strip wound together and insulated with paper. Two of these spirals, one with mercury contacts and one without, made by Henry himself, are

shown in Fig. 3. His paper, published in 1832, shows that he had independently rediscovered, very shortly after Faraday, the fact of the mutual induction of electric currents. In his investigations into the induction of a current on itself, he went further than Faraday; and by interposing his body between the terminals of the secondary circuit, he showed that a very perceptible shock could be obtained when the primary circuit was broken; and he also showed that up to certain limits this shock became greater as the lengths of

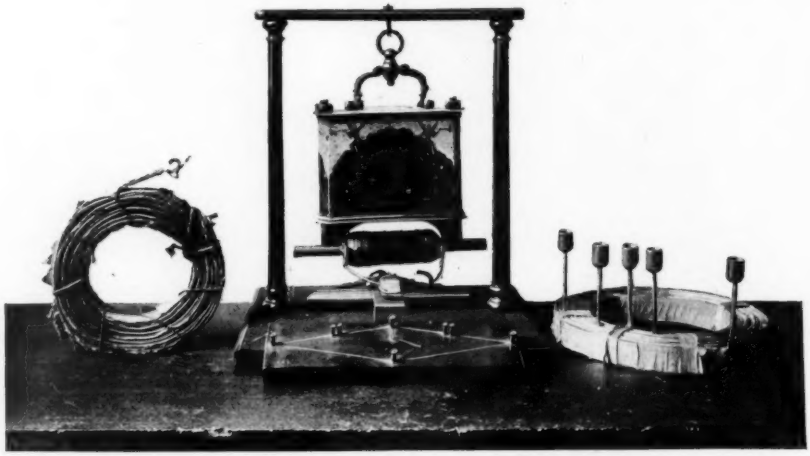


FIG. 3.—PROFESSOR DANIELL'S LODESTONE LENT TO FARADAY, WITH FARADAY INDUCTION COIL ATTACHED. ORIGINAL WHEATSTONE BRIDGE. TWO OF JOSEPH HENRY'S ORIGINAL INDUCTION COILS. (WHEATSTONE MUSEUM, KING'S COLLEGE, LONDON.)

the coils were increased, though the spark obtained on breaking the circuit, without the intervention of the body, was thereby diminished. To Joseph Henry, therefore, is to be given the credit of the discovery of self-induction; and Prof. Fleming considers that the modern transformer should rather be considered as the descendant of the Henry coil than of Faraday's type wound with wire.

In 1833 a most important advance in electrical measurement was reached by the publication by Gauss of a paper describing the theory and method of measuring the intensity of terrestrial magnetism, and the strength of a magnetic pole, in absolute measure—that is to say, in terms of units depending only on the units of space, time, and mass which were chosen. Those adopted by him were the millimetre, the second, and the milligramme.

Faraday's researches during this and the following year were principally in the domain of electro-chemistry, and resulted in establishing the two fundamental laws of electrolysis, namely—

1. The amount of chemical change which takes place in any electrolytic circuit is directly proportional to the quantity of electricity transferred through the circuit.

2. For the same quantity of electricity transferred through any circuit, the amounts of the different electrolytes decomposed in that circuit, and therefore the amounts of the ions set free, are proportional to the chemical equivalents of these different electrolytes or ions.

An important portion of this electro-chemical work was comprised in the researches on the "Electricity of the Voltaic Pile," completed in April, 1834, in

which he disproved completely Volta's contact theory of the origin of the electromotive force in a cell. He showed that the chemical and electrical effects were proportional to one another, and inseparable, and he discovered a way of making a cell without metallic contacts at all.

Faraday, in the final argument he brought to bear against the contact theory, clearly set forth the doctrine of the conservation of energy. It was not, it is true, the first time that this doctrine had been stated, for George Green had definitely formulated it in 1837, in a paper on The Reflection and Refraction of Light at the common Surface of two non-crystallised Media, the reasoning in which is based on the following proposition:—"In whatever way the elements of any material system may act upon each other, if all the internal forces exerted be multiplied by the elements of their respective directions, the total sum for any assigned portion of the mass will always be the exact differential of some function." This is a perfectly clear statement in mathematical language of the principle of the conservation of energy, the function being what is now known as potential energy, and the statement is simply equivalent to saying that the sum of the potential and kinetic energies of the system is constant. Later on in the paper, Green gives as the reason for this assumption that otherwise "a perpetual motion would be possible, and we have every reason to think that the forces in Nature are so disposed as to render this a natural impossibility." This remarkable statement, in common with most important propositions of the same author's in the mathematical theory of electricity, attracted little or no attention until years afterwards, when most of them had been rediscovered by others. They would certainly not be known to Faraday, who was not a mathematician.

Want of space precludes more than the mere mention of his important discovery, made in 1845, of the rotation of the plane of polarisation of a ray of polarised light, traversing a magnetic field in the direction of the lines of force; and his wonderful forecast, published in 1846, of the electromagnetic theory of light, developed, eighteen years later, by Clerk-Maxwell.

In the year 1840, Joseph Henry made the important discovery that the discharge of a Leyden jar, and hence any kind of electric discharge, was in general of an oscillatory character, the result being deduced from the puzzling anomalies observed in the direction of magnetisation of steel needles enclosed in helices traversed by Leyden jar discharges.

In 1843, Sir Charles Wheatstone published an important paper, describing various methods of measuring electrical resistance, including the apparatus now

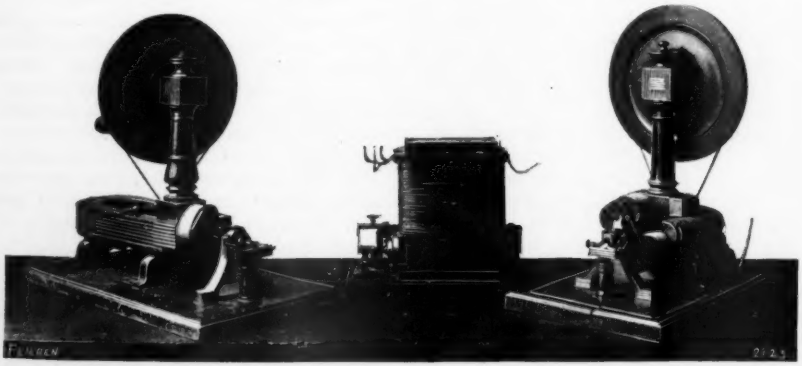


FIG. 4.—EARLY SAXTON MAGNETS. MODIFIED FORM WITH ELECTRO-MAGNET. WHEATSTONE'S FIRST DYNAMO. (WHEATSTONE MUSEUM.)

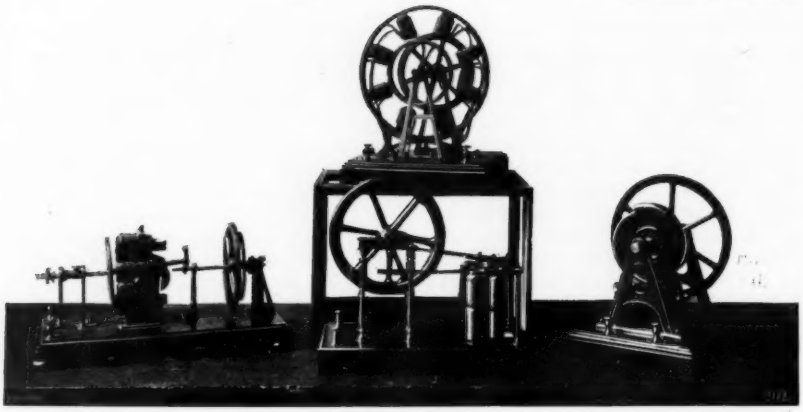


FIG. 5.—EARLY WHEATSTONE ELECTRO-MOTORS. (WHEATSTONE MUSEUM.)

known as the Wheatstone Bridge. An early form of this, constructed for his own use, is shown in front of the Daniell Lodestone, in Fig. 3.

Meanwhile, the mathematical treatment of Faraday's experimental facts, although developed in accordance with the old theory of action at a distance, continued to bear important practical fruit. In the year 1846, Ampère's investigations on the mutual actions of conductors carrying electric currents, led Weber to the invention of that important measuring instrument, the electro-dynamometer; and in 1851 and subsequent years, Weber, who had been associated with Gauss in his magnetic measurements, developed a definite system of electrical measurement expressed in terms of absolute units, and founded upon Gauss's absolute system of magnetic measurement. In a paper published by him in 1851, he pointed out that, according to Ohm's law, the resistance of a closed circuit is determined in terms of the E.M.F. and the current strength, and he proceeded to define the unit of resistance as the resistance of a closed circuit in which unit E.M.F. produces a current of unit strength. He then went on to show that E.M.F. and current strength require for their expression in absolute measure the determination of the strength of a magnetic pole, and of the intensity of terrestrial magnetism, both of which Gauss had shown how to determine. The advantages of Weber's system were at once recognised by Sir William Thomson, now Lord Kelvin, and in the year 1861 the appointment was made at his suggestion of the famous Committee of the British Association for the consideration of standards of electrical resistance, which ultimately developed into the consideration of the general problem of electrical measurement, and whose work culminated in October, 1881, when the Paris International Congress of Electricians decided that the system so developed should be adopted by electricians throughout the world.

Owing to the limited space at my disposal, I shall confine my attention to those applications of electricity which have been called "heavy electrical engineering," and which may be subdivided into three sections as follows:—

1. The production of light and heat, in which the energy is utilised in the form of luminous vibrations in the ether; and heat vibrations, either in the ether or in the molecules of matter.

2. The transmission of mechanical energy for driving machinery, which may be in a fixed position relatively to the source of electric energy, as in the case of factories and of boats and cars driven by accumulators; or may be in motion relatively to it, as in the case of electrically-

driven cars receiving their energy from a fixed station.

3. The application of electrical energy to the production of chemical change for such purposes as the electro-deposition of metals, the refining and reduction of certain metals from their ores, and the manufacture of certain compounds.

The methods of distributing the power will not be affected by the final form in which it is to be applied, but some modifications must necessarily be introduced when the load is in motion relatively to the source of power.

Attempts to utilise electrical energy for the various purposes enumerated above were made very soon after the discovery of primary batteries, but their maintenance is far too costly for them to be commercially employed for the generation of power in large quantities, so that none of these early attempts passed beyond the laboratory or experimental stage, until Faraday's electro-magnetic discoveries led the way to a more economical means of generating electrical energy, in the shape of what is now known as the "dynamo." Since, generally speaking, modern electro-motors, or machines used for re-transforming electrical into mechanical energy, are nothing more or less than dynamos, it will be convenient to consider together the development of dynamos and electro-motors, which latter, as we are now considering only electrically-driven motors, I shall in general, for the sake of brevity, designate simply as motors. Before proceeding further, it may be well just to call to mind the fundamental principles of the dynamo and motor respectively.

(1) Any metallic circuit in motion in a magnetic field will have an electric current induced in it proportional in strength at any moment to the instantaneous change-rate in the number of lines of force which it embraces.

(2) An electric circuit, if free to undergo changes in configuration or position, will, when placed in a magnetic field, undergo such changes as will make it embrace the greatest possible number of lines of force; or, as we may express it, an electric circuit tends to enlarge itself.

(3) A magnetic circuit capable of changing its configuration tends to contract into as compact a form as possible.

(1) is the fundamental principle of the modern dynamo, and, indeed, of all magneto-electric generators; (2), of the modern motor; and (3), of some of the early motors; but motors depending on (3) were very soon abandoned, as their efficiency is always extremely low.

The first electro-motor was the apparatus with which, on September 3rd, 1821, Faraday discovered the electro-magnetic rotation of a copper wire round the pole of a steel magnet. Reproductions of Faraday's original sketches and descriptions, from his note-books, may be found, by those readers who wish to learn more of his work, in a recently issued charming little book by Prof. S. P. Thompson, under the title of "Michael Faraday: his Life and Work."

This was followed in 1823 by Barlow's star wheel, modified by Sturgeon into the more reasonable form of a disc, with its edge between the poles of a steel magnet, and which was set in rotation when traversed by a current from the centre to the circumference.

More elaborate rotary motors, depending on the contractive tendency of a magnetic circuit, were constructed in 1831 by Jacobi, who employed one in driving a launch; and in 1834 by Ritchie; while Joseph Henry in 1831, and Dal Negro in 1833, devised motors of an oscillatory type.

In 1835, Davenport, an American inventor, devised a motor which partially anticipated the later designs of Froment, and employed it in driving a model car, carrying batteries, on a small circular railway.

In 1838, Page, another American, constructed a motor with a coil and plunger mechanism, and used it for driving a lathe; and, in the same year, Davidson, a Scotchman, constructed a powerful motor, weighing, with its battery of forty cells, some five tons, which he fitted up on an ordinary railway truck, which made successful trips on several of the Scotch lines.

Wheatstone, in 1841, constructed a number of different motors, four of which, selected from a number now in the

Wheatstone Museum at King's College, are illustrated in Fig. 5. In the lower central one two electro-magnets are alternately energised by the current, and by the attraction of their armatures produce, by means of cranks and connecting-rods, a rotation of the fly-wheel, the energy of which carries the machine past the dead points. The other three machines show various modifications of a device of Wheatstone's, by which, as the machine rotates, portions of an iron disc or ring approach and recede from two or more electro-magnets, which are successively energised during each rotation, and it will be seen that in consequence of the tendency of the magnetic circuit to contract itself, this will result in continuous motion. Froment constructed his first motor in 1834, and later developed the well-known form based on the plan of fixing upon the rim of a rotating wheel a number of bars attracted laterally to the poles of an electro-magnet, the current in which was automatically cut off just before the approaching armature had attained the position of least distance, and turned on again as soon as its attraction for the next approaching one would be greater than for the one receding.

In 1845, Hjörth, a Dane, being at Liverpool, devised a very ingenious arrangement, consisting of a pair of electro-magnets, with ends in the form of hollow, truncated cones, one of which plunged into the other. This arrangement gave a strong pull over a range of over 5 ins., the pull ranging from 160 to 72 lbs over this range, and was awarded a gold medal at the Great Exhibition of 1851. Page, like Davidson, was strongly convinced of the applicability of the electric motor to railway work, and in 1851 he built a ten h.p. electric locomotive energised by means of a battery of 100 large Grove cells carried by the locomotive, which attained a speed of 19 miles an hour on the Washington and Baltimore line. The cost, as in Davidson's experiments, was of course prohibitive.

In 1864, Pacinotti produced a machine having a ring armature with coils of copper wire wound on equi-distant projections placed round the rim, which was the forerunner of the modern electro-motor, and brings to an end for a time its separate development, as the next great improvements were effected by inventors who were not trying to design motors at all, but to perfect current generators, and in so doing found themselves in possession of very much better motors than any which had been designed as such.

The first continuous current electro-magnetic generator was Faraday's disc of 1831, already referred to, and shortly afterwards he constructed a machine consisting of a rectangle of wire, which, when rotated in the earth's magnetic field, gave rise to alternate currents, which therefore formed the first alternate current electro-magnetic generator.

In 1832, Pixii devised a machine in which a steel magnet revolved over fixed coils of wire wound upon a horse-shoe core of soft iron; and in the following year Saxton invented the form shown on the left-hand side of Fig. 4, which is a photograph from instruments in the Wheatstone Collection; a mercury collector was employed in place of a sliding contact. A later form is seen on the right of the illustration, in which the compound steel magnet is replaced by an electro-magnet energised by a battery.

In 1838, Sturgeon introduced a shuttle-wound coil placed longitudinally between the poles of a steel magnet, and a two-part commutator. Wheatstone and Cooke, in 1841, first grouped the coils in such a manner as to produce, with a commutator, a practically continuous current; and in 1845 they took out a patent for the use of electro-magnets in the place of permanent steel magnets.

In 1848, Jacob Brett suggested that the current generated in the armature by the permanent magnetism of the field magnets should be sent through a coil of wire surrounding the latter, so as to increase their strength. This appears to be the first suggestion of the principle of the self-exciting dynamo. Pulvermacher, in the following year, introduced the use of thin laminated iron for the armature cores, and in 1851 Sinsteden used bundles of iron wire for the same purpose, and also independently made the same suggestion that Brett had made three years earlier.

In 1849 Nollet, assisted by Van Mal-

deren, designed an alternate current machine, which after his death was developed by Holmes, Masson, and du Moncel, into the well-known Alliance Machine, which was largely employed in France for lighthouse illumination. Holmes continued to introduce further improvements, and at the International Exhibition of 1862 he exhibited a direct-current machine with a large commutator, and rollers for collectors. This machine had 160 bobbins arranged upon the rims of two wheels 9 ft. in diameter, with sixty steel horseshoe magnets arranged in three circles. In 1867 he remodelled this machine, doing away with the commutator and diverting the current from a few of the coils to increase the strength of the field magnets. Hjörth, in 1855, had taken out a patent for a machine with permanent steel magnets giving the initial current for the excitation of powerful electro-magnets. In 1856 C. W. Siemens constructed a machine with the iron-cored shuttle-wound armature, designed by Werner Siemens; and in 1863 Wilde made a machine, with Siemens's armature between the poles of electro-magnets, excited by means of an auxiliary magneto machine with a similar armature.

In 1866 Murray, Farmer, and Baker, all made use of exciting coils on steel field magnets; and C. and S. A. Varley applied for a patent for a machine using electro-magnets only initially excited by means of permanent ones. In 1867 Werner Siemens suggested that the initial excitation might be obtained by means of a battery, and very shortly afterwards both he and Wheatstone discovered independently that the residual magnetism of the iron cores was sufficient, and so invented the self-exciting dynamo. The two papers announcing this discovery were communicated to the Royal Society within a few days of each other, and were read on the same day, Wheatstone's paper proposing the use of a shunt-exciting coil, while Siemens used a series coil. The term dynamo-electric machine, now shortened into dynamo, was suggested by Siemens in this paper. Wheatstone's original machine is shown in the centre of Fig. 4.

Gramme in 1870 devised his ring armature, which only differed from Pacinotti's in the absence of the projections and in having the coils all the way round, and very soon afterwards Gramme began to put actual commercial machines on the market.

According to M. Figuier, the Gramme Company had two machines exhibited at the Vienna International Exhibition of 1873, and one day, while one of them was in motion and the other standing still, a workman, seeing some cable-ends lying loose upon the floor, fancied that they belonged to the machine at rest, and placed them in its terminals, when, to the astonishment of everybody, the armature of the machine began to rotate, being driven by the current from the other machine; and it was in this manner that the inter-convertibility of generators and motors, which had been pointed out by Lenz in 1838, and again by Jacobi in 1850, was re-discovered, and immediately put to practical use.

In 1875, Van Hefner Alteneck introduced the important improvement on the Siemens armature of windings spaced at symmetrical angles. In 1877, Gramme designed an alternator with a multipolar ring armature, which was followed in 1877, 1878, and 1879, by Siemens and Halske's disc armature alternator, the same firm's drum armature machine, a very similar one by Schuckert, and De Meritens', with a ring armature. In 1878, Brush invented the system of compound winding for continuous current machines. The disc armature alternator, now so well known as the Ferranti machine, was independently invented by him and Lord Kelvin in 1881.

The next important improvement in continuous-current machines was made in 1883 by John Hopkinson, and consisted in making the magnetic circuit more compact, the advantage of which he had demonstrated theoretically. In the same year the first commercial alternator of the inductor type was exhibited by Klemenko at the Vienna Exhibition.

In the year 1879, Walter Bailey exhibited to the Physical Society of London a little motor in which an Arago disc was made to rotate by progressively shifting

the magnetism between the four successive poles of the electro-magnets, in other words, by means of a continuously rotating magnetic field, which was produced by an ingeniously constructed commutator turned by hand, and a current from a battery of four dry cells. This discovery did not, as a matter of fact, lead directly to any practical result, but it is of great interest as being the first polyphase motor.

In the following year Marcel Deprez actually constructed a motor which was driven by means of artificially-produced polyphase currents, but not with a rotary field. Three years later he showed theoretically that a rotary magnetic field could be produced by the combination of two alternating currents differing in phase by a quarter period.

In 1885, Professor Galileo Ferraris independently arrived at the results worked out both by Bailey and Deprez, and in 1888 described some simple forms of motor, and the means of getting two-phase currents from an ordinary alternating circuit. In the meantime, Nicola Tesla had been working independently at the same subject since 1886, and in 1887 had applied for a number of patents for polyphase motors of practical form.

In 1888, Mordey introduced a form of alternator of an improved inductor type, in which both the armature and the field windings were fixed, and the field magnets which formed the revolving portion were made of a specially designed form, giving a single and compact magnetic circuit. One of the most recent of these machines, having an output of 400 kilowatts, and directly coupled to a compound twin Raworth

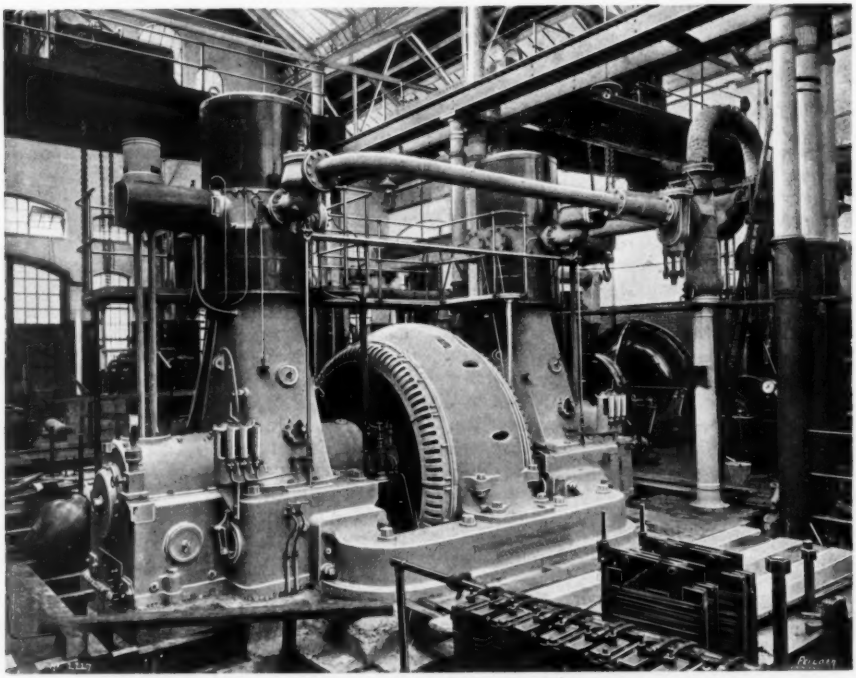


FIG. 6.—MORDEY ALTERNATOR DRIVEN BY RAWORTH UNIVERSAL ENGINE. (BRUSH ELECTRICAL ENGINEERING CO.)

Universal Engine of the enclosed type, is shown in Fig. 6.

The first polyphase generator, a three-phase machine, was designed by C. E. L. Brown, and built by the Oerlikon Company of Zürich in 1891.

Any continuous-current dynamo, if supplied with current, will act as a motor, and an alternate-current machine, if once run up to the proper speed, which depends on its construction and on the periodicity of the current supplied, will continue to run and supply power as a motor, unless overloaded to an extent which makes it break out of step, when it will be pulled up, and will not continue to give out power until again run up by external means to the proper speed. Motors of this kind are called synchronous motors, on account of the synchronism maintained between the generator and the motor.

Polyphase motors can be started from rest by switching on current in the same manner as continuous ones, and there are numerous single-phase motors now in use in which the device of Prof. Ferraris is employed for starting, namely, the current is divided into two portions differing in phase, and these are sent through two windings so arranged as to produce a rotating field until the motor has run up to speed, when the starting device is usually cut out, and the motor supplied with single-phase current.

One of the best of these is the Langdon Davies Motor, which was invented in 1895, and is now in very extensive use. The splitting of the phase is accomplished by making part of the current flow through an inductive resistance which causes the phase in that part of the circuit to lag behind the other.

Motors have been employed in which a condenser is used in place of an inductive resistance, which gives a lead instead of a lag in phase, but durable and otherwise satisfactory condensers for such purposes have yet to be devised. In 1898 a self-starting motor was invented by Heyland, in which the lag is produced without any separate starting gear, by a very ingenious method of winding the starting coils in such a manner as to permit of a considerable amount of leakage self induction, with the result that currents with considerable lag are induced in this closed winding.

In the year 1893, Sayers introduced an important modification in the design of continuous-current dynamos which had the double effect of maintaining, with a varying load, a constant E.M.F. at the terminals without the use of compound winding, and of obviating the necessity of shifting the brushes as the load varies in order to prevent sparking.

Figs. 7 and 8 illustrate two of the most recent types of continuous-current motor

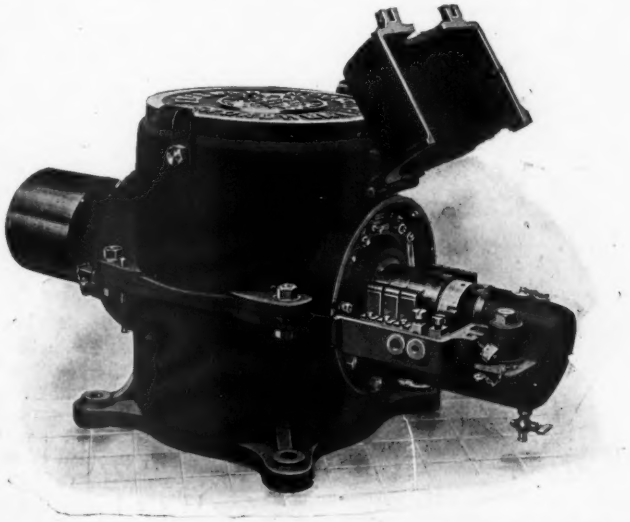


FIG. 7.—ENCLOSED TYPE CONTINUOUS CURRENT ELECTRO-MOTOR. (EDISON SWAN CO.)

which have been put on the market, the former being a two-pole completely enclosed motor, built by the Edison-Swan United Electric Light Company, and the latter a slow-speed multipolar motor, by the British Schuckert Company. I must not close this account of the development of the modern dynamo without making brief reference to some of the workers who have added to our knowledge of the physical phenomena which underlie the theory of dynamo and motor construction, and have assisted in the development of the theory so as to make it possible, as at present, to design machines to fulfil predetermined conditions.

Beginning with Poisson's investigations into induced magnetisation at the beginning of the century, Lenz's researches in 1834, Weber and Neumann's investigations of the conditions of electro-magnetic induction in 1846 and 1847, and the researches into the theory of both generators and motors, extending from 1838 to 1857, of Poggendorff, Joule, Jacobi, Sinsteden, Koosen, Favre, and Le Roux, we come to the noteworthy epoch in 1867 of Wheatstone and Siemens's introduction of the self-exciting machine, and in the same year Maxwell published a short but suggestive mathematical paper, which did not at the time receive the attention which it deserved. Little attention seems to have been given to the theoretical side of the matter for the next ten years, but since then we find valuable work done by Mascart, Hagenbach, Joubert, Kapp, Kelvin, Rucker, Esson, Mordey, and, above all, John Hopkinson, who published his first great paper on the theory of the dynamo in 1879, demonstrated in 1884 the theoretical possibility of running alternators in parallel, which was very shortly afterwards carried into practical effect; and in 1886, in conjunction with his brother, Edward Hopkinson, worked out the method of predetermining the characteristic curve of a dynamo. A very important part was played by the magnetic researches of Hughes, and, later, of Ewing; and worthy also of special mention are the working out by Ayrton and Perry in 1882 of methods for making continuous current motors self-regulating for constant speed; and the splendid work of the American electrician Steinmetz, which has done so much to assist in the improvement of alternate-current machinery. In alternate-current work, both as applied to machine construction and to problems of distribution, electrical engineers have also to acknowledge their great indebtedness, in addition to Steinmetz, to the splendid mathematical work of Oliver Heaviside, Lord Kelvin, Lord Rayleigh, and many others.

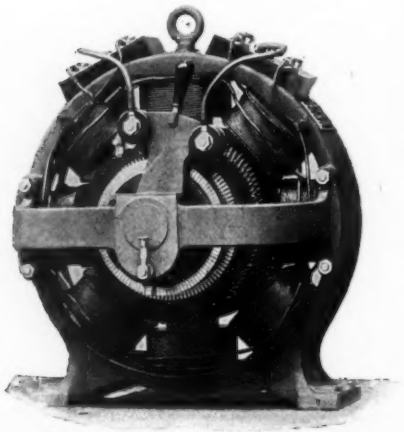


FIG. 8.—MULTIPOLAR CONTINUOUS-CURRENT MOTOR. (BRITISH SCHUCKERT MOTOR.)

The first purpose for which large magneto-electric generators were designed was for the illumination of lighthouses by means of the electric arc, which was originally obtained by Sir Humphry Davy in 1809. For a good many years after this the arc light was only employed for experimental and lecture purposes, and the various automatic lamps devised for the purpose of maintaining a steady arc by means of some kind of electro-magnetic mechanism, actuated by the current, were all exceedingly complicated in structure, and the regulation was extremely imperfect. It was probably for this reason that the first street lighting by electricity, viz., that of the Avenue de l'Opéra in Paris, in 1878, was carried out, not by arc lamps, but by means of the so-called Jablochkoff candle, in which the

two carbons were placed parallel to each other, and separated by a thin strip of porcelain insulating material which burned away with the carbons. In order to start the arcs when the current was turned on, the candles were tipped with a paste of powdered carbon and gum. These were also employed on the Victoria Embankment in London, and in many other places. They were not, however, satisfactory, the light being extremely unsteady, and, moreover, if accidentally put out through interruption of the current, they would not re-ignite. These first attempts at street lighting served, however, to direct the attention of numerous inventors to the improvement of arc lamps, and very shortly afterwards arc lighting began to be employed, the Brush lamp being one of the earliest forms used for the purpose. In the meantime the invention of the incandescent lamp in 1878 and 1879 by Lane Fox, Edison, and Swan, gave a great impetus to electric lighting. The history and manufacture of the incandescent lamp have already been treated in FEILDEN'S MAGAZINE (March, 1900), so that I will not further consider it here, and want of space precludes the discussion of the various improvements in arc lamps, and of the development of ornamental interior lighting which has been made possible by the introduction of the incandescent lamp.

Electric heating by means of radiators formed of wire grids embedded in insulating material, and traversed by an electric current, is largely used in America for car-heating, and is coming into use in this country for warming theatres and other public buildings where the heat is only required during a few hours in the day.

With the extension of cheap electric energy, we may expect both these radiators and the various electric cooking appliances, which depend on the same principle, to come into extensive use for domestic purposes.

The industrial applications of electrically-generated heat to the working of metals I have considered in recent numbers of FEILDEN'S MAGAZINE, and will not therefore recapitulate them here.

It is now some ten or twelve years since electro-motors began to be used on a considerable scale for factory driving, both in the United States and in Switzerland, water-power being the source from which the energy was obtained. The experience gained, however, soon showed that in very many cases great economies could be effected even in large steam-driven factories by replacing the various isolated steam engines by one large one used to generate electric power for distribution to motors in the different shops. For this purpose, polyphase or single-phase alternate current motors are, in general preferable to continuous current ones, as, owing to the absence of a commutator, they require less attention and are less liable to get out of order. Owing to the entire absence of sparking, they may, moreover, be employed in places where the continuous current motor would be inadmissible.

The energy required for driving electric generators is most commonly obtained from some combustible substance, of which coal, being the most generally available, is most largely used. The prime movers, or machinery by which the first transformations of energy are effected, are usually steam engines; but gas engines are much used for small power stations, and as some of the more recent types have been so much improved as to be capable of economical use in much larger sizes than formerly, their employment is extending to larger stations. When water-power is readily obtainable it is generally cheaper to utilise it; and this is usually effected by means of turbines or Pelton wheels.

In the earlier steam-power stations the dynamos were usually driven by means of ropes or belts, heavy fly-wheels being employed to obtain the maximum amount of steadiness; but the improvements in high-speed steam engines, which have mainly been made in response to the requirements of electric generating machinery, led to direct driving by means of high-speed engines coming into pretty general use some ten years ago, and now it is practically universal.

The most recent practice is to build the moving portion of the dynamo round the fly-wheel, as was, I believe, first done by

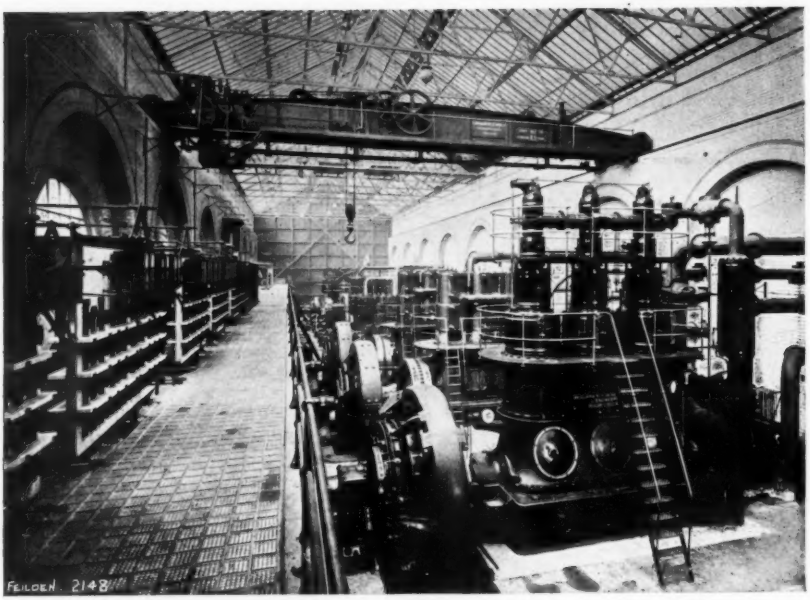


FIG. 9.—PORT DUNDAS ELECTRIC POWER STATION OF THE GLASGOW CORPORATION.

Ferranti at Deptford, or, what comes to the same thing, to build it massively enough to act as a fly-wheel. This is illustrated by the machine nearest to the point of view in Fig. 9, which is from a photograph of the Port Dundas Electric Power Station of the Glasgow Corporation, which was opened in September last. This is a twelve-pole continuous-current compound-wound machine, built by Messrs. Crompton, having a normal output of 1,100 h.p., and driven by a Willans three-crank triple-expansion engine. Immediately behind this are seen two other 1,100 h.p. sets, each consisting of a British Thomson-Houston compound-wound multipolar dynamo driven by a Belliss six-cylinder triple-expansion engine. Each of these three sets is designed to give an overload output, with of course a slight loss of efficiency of 1,500 h.p., to help the station over the peak of the load line.

In the earliest cases of distribution of electrical energy the generator was employed to supply a single absorbing device, or receiver, such as a lamp or a motor: for example, until the comparatively recent opening of the municipal electric works at Blackpool, each of the lamps on the front had its own dynamo and circuit. The next step was to use a larger dynamo to supply several receivers, each having its own separate circuit.

The quantity of energy transmitted in a second across any section of a circuit carrying a steady current is equal to the product of the electric pressure or voltage by the electric current or amperage, the latter being measured by the quantity of electricity crossing a section in a second. The amount of energy delivered in a given time may therefore be varied by varying either or both of these factors. The variation of both factors, however, generally introduces undesirable complications, and therefore either the current or the pressure is kept constant. The former method was the one first used, and for arc lamps for street lighting it is best to have all the lamps connected in

series and traversed by the same current, as lamps supplied with constant current can be regulated more economically than those supplied at constant pressure. In the early stages of electric lighting arc lamps that would burn steadily on constant pressure circuits had not been devised, so that the series, or constant-current, system was necessarily employed for them, and for supplying current to a group of arc lamps which are all lighted and put out simultaneously it is very suitable; but there are two reasons which prevent its use for the general purposes of electric supply. In the first place, the total voltage is equal to the sum of the voltages taken by the different receivers, so that if a consumer had, say, 25 lamps, each taking 40 volts, the total pressure between the mains entering and leaving the premises would reach the dangerous amount of 1,000 volts; secondly, when the load is varied by throwing out some of the lamps, these have to be short circuited to prevent the others being put out, and unless wasteful resistances are introduced this lowers the resistance of the circuit, necessitating a reduction in the pressure delivered at the dynamo terminals, and the requisite pressure regulation is invariably attended with difficulties involving either loss of economy or danger of damage to the commutator.

In a supply at constant pressure there is no difficulty in regulation since the introduction of compound winding, which maintains the pressure sensibly constant for wide variations in the load. In this system the receivers are all connected in parallel across the mains, and therefore it is known as the parallel system of distribution.

The theoretical possibility of a distribution of this kind was understood long before the mention of the dynamo, but, as already explained, there were no arc lamps suitable for such circuits, and the earliest incandescent lamps were of such low resistance that the pressure of the supply would have been so low as to make the cost of the conductors prohibitive. The size of a wire connecting two stations between which electrical energy is to be transmitted is determined, not by the amount of energy transmitted, for the energy, as before explained, is not carried by the wire, but by the heating effect of the current set up in the wire, and the higher the pressure of supply the greater is the economy in copper for the conductors. When, however, Lane Fox, Edison, and Swan had succeeded in producing incandescent lamps that could be used with pressures of 50 to 100 volts parallel distribution became practicable.

In any portion of a circuit carrying an electric current the difference of pressure at its extremities is, by Ohm's law, equal to the product of its resistance by the current which it carries, so that the difference of pressure between adjacent points of a pair of mains from a supply station will diminish as the distance from the station increases. The result of this will be that if similar lamps are used throughout, those nearer the source of supply will be brighter than the more distant ones. This pressure drop can be diminished to any extent desirable, either by diminishing the resistance of the mains by increasing their size, or by diminishing the amount of current accompanying a given transfer of energy by increasing the pressure of the supply. The former process is limited by the large expenditure which would be involved in indefinitely increasing the size of the mains. One way in which an economy may obviously be made is by using mains of large section near the station, and gradually diminishing their size as their distance increases and they have to carry less current, due to a continually increasing portion of it flowing back through the intermediate lamps and other receivers on the circuit. Another method is Edison's feeder and main system, first introduced in the United States, but now universally employed. It consists in subdividing the area to be supplied into a number of districts, each of which is connected with the station by a pair of mains called feeders, to which no customers are connected. From the points supplied by the feeders, distributing mains are run in different directions in order to supply customers. When the area of supply does not consist of scattered districts, but is practically continuous, these distributing mains are usually connected together, so as to form a complete net-work, supplied

with energy at different points by means of the feeders. The pressure at the further ends of all the feeders is maintained constant. This might be effected by having each feeder supplied by a separate dynamo and varying the pressure at the terminals of each machine by hand regulation at the central station; but this would involve the use of a large number of small machines, which, moreover, would usually be very unequally loaded at different times, and the usual practice is to supply all the feeders from a common pair of "bus" bars at the station. The bus bars are supplied in parallel from a number of similar dynamos, the number varying with the load. Small auxiliary dynamos known as "Boosters" are employed to supply the additional energy required to overcome the resistance of the feeders. The feeders can be switched on or off the bus bars as required by the distribution and amount of the load, the pressure at the feeding points being ascertained by means of the station instruments. In the earlier instances of alternate current supply, each circuit was supplied by a separate machine, and although the possibility of running alternators in parallel was demonstrated by Dr. Hopkinson in 1886, it was not until 1891 that it was first put into practice with the Mordey alternators at Bournemouth and the Elwell Parker machines at West Brompton, and another year elapsed before it came into general use.

The pressure on the distributing mains was until very recently limited to 100 volts, owing to no low-candle-power incandescent lamps being available for higher pressures; but lamps as low as 8-candle power are now made for pressures up to 250 volts, and they are very nearly as satisfactory as the old 100-volt lamps, and many of the supply companies have in consequence increased their pressure, enabling them to supply more current from the same system of mains, and consequently to reduce the price.

In 1882 Dr. John Hopkinson devised the three-wire system, in which two dynamos are connected in series, and maintain between two outer mains a pressure double that required for use in the lamps and other receivers, which are connected, not across the mains, but from one or other of them to a third wire, which comes from the common terminals of the two machines.

The third wire then acts as a return for each of the others; but the current carried by it is only the difference in the current taken by the receivers which may be in use on the two outers at any time, so that it may be made of comparatively small section.

It is necessary to maintain an accurate balance on the two outer mains, because any difference in the load causes a rise in pressure on the more lightly loaded side, and this is usually effected by means of a motor dynamo consisting of two armature coils wound on a single drum, the two windings being in series, and connected across the mains, while the balancing wire is connected to their common terminal. The effect of this is that when one side is overloaded current passes through the other armature, driving it as a motor, and causing the winding on the overloaded side to give out a current which approximately makes up for the extra load.

When the district supplied from a central station covers any considerable area, an economy in copper is usually effected by distributing at high pressure to a certain number of sub-stations, and transforming down at these sub-stations to the pressure required for house-to-house supply.

When continuous currents are employed, the transformation is effected by motor generators, which consist of a combined motor and dynamo, the motor being driven by the high-pressure current and the dynamo supplying current at the lower pressure. If the distances are great, alternate currents, either monophase or polyphase, are usually preferred, as static transformers can then be employed, and very high pressure is possible for the long distance transmission. In the Deptford to London transmission the pressure is 10,000 volts, and in the United States pressures as high as 16,000 volts are in use. Generators could not be economically built to give such high pressures directly, so that low-pressure dynamos

with step-up transformers are generally used at the station, and the pressure is reduced again by means of step-down transformers at the other end.

The Faraday ring and straight core induction coils, shown in Fig. 1, are the earliest examples of closed circuit and open circuit transformers respectively, while the Henry coils shown in Fig. 3 are examples of transformers without iron cores.

In 1856 C. F. Varley devised induction coils for telegraphic purposes in which a ring-core of iron wires was employed. Between 1877 and 1882 proposals were made to use induction coils for distribution of the electric light, and various modifications were introduced by Jablochkoff, Fuller, de Meritens, Gordon, Desprez, and, lastly, by Gaulard and Gibbs. All these inventors proposed placing a number of these transformers in series in the same primary, the impracticability of which, owing to reactive effects on the primary circuit, followed from Faraday's experiments in 1834, and had been theoretically proved by Clerk Maxwell in 1865. The two last-mentioned inventors, however, deserve the credit of calling attention to the value of transformers by their persevering attempts to introduce them for practical purposes, which was made possible in 1885, when Messrs. Zipernowsky, Déri, and Bláthy worked out the conditions for the employment of transformers in parallel, and introduced further improvements. Other workers who have made important contributions to the improvement of the transformer are John and Edward Hopkinson, Rankin Kennedy, Ferranti, Swinburne, Mordey, and others. A large transformer, recently constructed by the Westinghouse Company, is shown in Fig. 10.

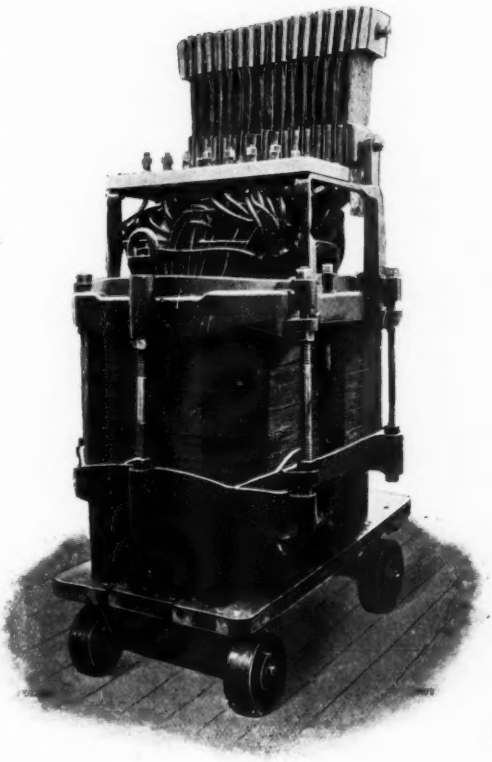


FIG. 10.—450-KILOWATT WESTINGHOUSE TRANSFORMER, BUILT FOR THE ACHESON GRAPHITE CO., NIAGARA FALLS.

In the early stages of electric lighting the currents to be carried were comparatively small, and the conductors were usually carried on poles supported on insulators, as in the case of telegraph lines. For the transmission of electric power over considerable distances at high pressure, bare conductors supported on poles are still commonly employed in crossing open country; but in towns the usual method which in this country is universal, is to lay the conductors underground.

This is carried out in many different ways, among which I may mention: Bare copper strip, supported upon insulators within a conduit; insulated cables sheathed in lead and armoured with steel strip, laid down in trenches without further protection; insulated cables with or without lead sheathing to preserve them from moisture, laid

in concrete or other material permanently built round them; insulated cables drawn into conduits, and which can be drawn out and replaced when desired. Various insulating materials are employed, among the best being high-grade rubber and paper soaked in resinous oil.

In the case of alternating current conductors the use of any metallic sheathing causes appreciable loss owing to the production of induced currents in the sheath, and if iron is employed the loss becomes considerable on account of its magnetic properties. If, however, the cable is of the concentric type, either the inner or outer portion forming the outgoing lead, and the other the return, a sheathing may be employed without harmful effects.

In the case of alternating-current conductors, especially if the periodicity is high, thick solid conductors should not be employed, as the current does not penetrate beyond a certain depth below the surface, so if large conductors are used, the central portion is simply wasted.

The mains used by Ferranti between Deptford and London consist of concentric copper tubes separated and covered by an insulating compound, the whole being enclosed in iron sheathing. A less satisfactory but not unfrequently used method of counteracting this "skin effect" as it is called, is to strand the cables in such a manner that each strand winds in and out from the centre to the outside of the cable.

The reason that this is to a certain extent effective is that the current follows the strands to a considerable extent; and each of the strands in turn coming in contact with the insulating medium which carries the energy, is able to take it in without any screening action from surrounding metal.

The earliest suggestion of supplying electrical energy from a stationary source of supply to a moving load is to be found in a patent applied for in 1840 by Henry Pinkus for supply to trains in motion, most probably with a view to signalling; but the suggestion was made that an electro-motor might be used to drive the train. Model trains driven by motors from a fixed battery were constructed in 1847 by Lilley and Colton, of Pittsburgh, and by Hall, of Boston, in 1851. Further suggestions of a similar character were made in several patents for communicating with trains in motion, but until commercially practicable dynamos and electro-motors had been constructed no practical results were possible.

From 1875 to 1879, when he applied for a patent granted in 1891, George Green, an American mechanic, worked at the subject, using a battery, as he had not means to obtain a dynamo, and one of his model cars was capable of seating one or two people.

The first instance of such supply on a useful scale was its application to ploughing fields at Sermaize, near Paris, by Chrétien and Félix early in 1879, and in the summer of the same year the first electric tramway was erected by Siemens and Halske at the Berlin Industrial Exhibition. An electric locomotive and a single car ran on an oval track about 300 metres in circumference, the current being supplied by means of a third rail to a sliding contact under the locomotive. This was followed by the construction in America in 1881 of model tramways by Edison and Stephen Field.

The first commercial electric tramway was opened in May, 1881, at Lichterfelde, the third-rail method of supply being employed; and the next was the Portrush line in the North of Ireland. Then followed the Brighton line, constructed by Magnus Volk, and several German and Austrian lines constructed by Siemens and Halske.

After some further experimental work in the United States a tramway two miles in length was opened at Cleveland in 1884, the current being supplied through a slotted conduit; and this was followed in the same year by an overhead trolley line erected at Kansas City.

The first electric railway was the City and South London line, which was opened in 1890.

The Electric Street Railway of South Staffordshire, which was opened in 1892, was the first trolley line entirely carried out with British capital, and is noteworthy for the introduction of a side trolley-rod and improved form of base, introduced

by Mr. Dickenson, the engineer, and since generally employed where cars carrying outside passengers are in use, as it is then preferable to have the overhead conductor on one side instead of over the centre of the car.

The systems of supplying energy from the station to electric trams or trains may be divided into the overhead, the conduit, and the surface systems.

The system most commonly employed for tramway work is one with a single overhead wire, through which current is conveyed to the motors on the car or locomotive by means of a pole known as a trolley-pole, which is attached to the car in such a way that a wheel or metal cross-bar at its end shall always rest against the wire. The rails are bonded or welded together into a continuous circuit, which forms the return circuit.

The principal objection to the use of the rails as a return is that where continuous currents are employed, as is at present almost always the case, the leakage currents cause damage by electrolysis to neighbouring gas and water pipes. This may be overcome by the use of two trolleys and overhead wires; but this doubles the number of overhead wires and introduces considerable complication at crossings.

The overhead or trolley system is principally objected to on æsthetic grounds, and in order to meet this various systems have been devised in which the current is taken in underneath the car instead of from an overhead wire. The difficulty is then to stow the conductors where they will not interfere with ordinary traffic, or cause shocks to men and beasts coming in contact with them. As 500 volts is the pressure usually employed for traction work, the shock would be unpleasant to foot passengers, while its effects on horses would be disastrous, as the electrical resistance of a horse is much lower than that of a man, so that horses would be even more strongly affected than pedestrians.

One way of getting over these difficulties is to place the conductor in a conduit laid down the centre of the track; but, in this climate at any rate, it has not been possible to prevent mud and other matter being introduced through the opening through which the slider passes, putting the conductor in connection with the earth.

The Westinghouse and Schuckert Companies have overcome this difficulty by means of their surface systems, in which an insulated conductor is laid in a closed conduit below the centre of the track, and capable of being connected with a series of fixed contact studs projecting very slightly above the surface, and separated by a distance a little less than the length of a car. Contact between the car and the studs is effected by means of a shoe long enough to cover two studs at once. In order to prevent accidental shocks the studs are not permanently connected with the conductor, but are only rendered "alive" while the car is over them by means of an automatic electro-magnetic switch actuated by means of electro-magnets in the car. These systems seem to have worked well where they have been tried, in spite of the multiplicity of automatic switches.

Where a separate road-bed is available, as in the case of an ordinary railway, a third rail between the track rails is usually employed, the return current being carried by the track rails.

Variations on this are, the method now in use for the experimental conversion of part of the District Railway, in which two insulated rails are employed placed alongside the track rails, and the method employed for the Brighton Electric Tramway, in which the track rails are used as the outgoing and return leads respectively.

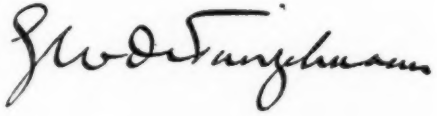
In terminating this brief and only too inadequate sketch of the development of the electrical engineering industry during the century which has just come to a close, I will venture to cast my eyes forward for a moment towards the vista of electrical progress in the Twentieth Century. The light of its early dawn as yet shows us only the veriest fringe of the prospect still covered by the veil of darkness, and as we faintly discern the as yet shapeless masses lowering through the gloom, we wonder how much of what we are looking for lies behind, and how much is to be utter surprise.

An important step was taken by Parliament last year towards encouraging the supply of electrical energy on a large scale, by the facilities granted to several new companies dealing with extensive areas, and their exemption from some of the more onerous restrictions of the Electric Lighting Acts, which have done so much to retard the utilisation of electrical energy. The carrying out of large schemes like these, deriving their supply of electrical energy from stations where coal is easily obtainable, and thereby cheapening it, should lead to a very much more extensive use of electric power. We may also hope before long to see the utilisation for the generation of electric power of some part at least of the enormous amount of energy continually being dissipated uselessly in the waste gases from the blast furnaces. Many workers are now engaged in seeking to improve the secondary battery, both in the way of increasing its efficiency and economy for stationary purposes, and in diminishing its weight relatively to output while retaining mechanical strength, so as to make it more widely applicable to automobile locomotion.

In the direction of electric lighting it does not seem unreasonable to hope that we may succeed in obtaining a solution of the problem, which Nature has already solved by the evolution of the glow-worm and the firefly, of directly producing electro-magnetic luminous waves without the accompaniment of whole octaves of heat waves which waste all but an infinitesimal proportion of the energy.

Another thing which we greatly desire, but of which, as yet, we can see no faint glimmering even of promise, is to find some less wasteful means of obtaining electrical energy than by burning coal in heat engines, whether, as many workers have been seeking, by means of a more direct transmutation into electrical energy of chemical energy stored up in some cheap and plentiful material such as coal, or, as is theoretically possible, by finding some means of utilising the enormous quantities of electrical energy of luminous vibration which are continually streaming from the sun into the ether which surrounds us on every side, and even permeates our bodies.

The problems of the constitution of the ether and of matter, and of their relations to each other, are now occupying many earnest and energetic workers ; and many mathematicians working in the profoundest depths of abstract thought are busily forging new and powerful tools, which the physicist and the chemist will shortly be applying, we trust with ever-increasing success, to the solution of some of the above-mentioned engineering problems, together with many others which as yet have not presented themselves even in the realm of speculative thought.



Marine Engineering and Shipbuilding.

By G. HALLIDAY, Wh.Sch.

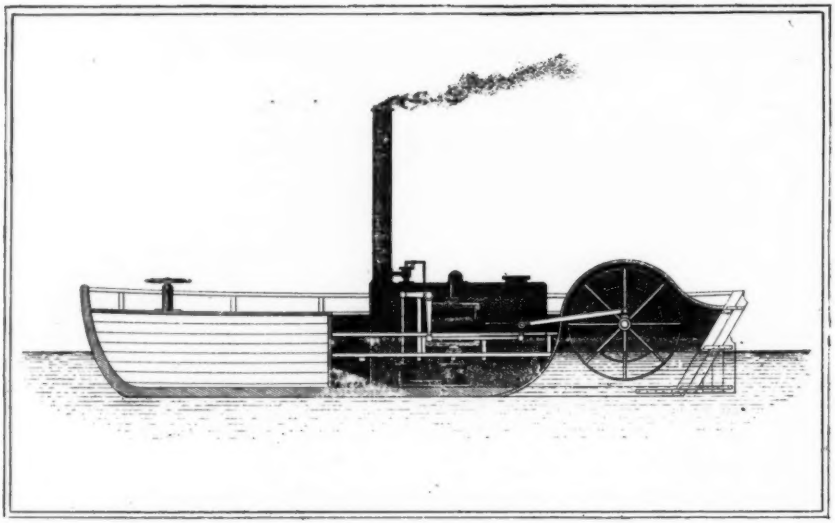
SINCE the days when the Phœnicians became ocean traders to the first year of the nineteenth century no progress had been made in shipbuilding or ship propulsion. During the whole of that period ships were built and sailed, but they were as strong, served the purposes of war as well, and carried as large cargoes at the beginning as at the end of it. And the management of those ships was quite as good at the beginning. No nation could produce sailors who could compete with the Phœnicians in loading a cargo, and none could approach them in the speed of their ships. The new era of modern shipbuilding and of ship propulsion began with the first year of the century, when William Symington fitted a Watt's engine to drive the stern paddle-wheel of the *Charlotte Dundas*. As it was due to Watt's improvements in the steam-engine that it was made possible to change the methods of ship propulsion, so it was due to the same cause that it was made possible to change the methods of ship-building. The invention of Watt's steam-engine made it possible to propel ships without the aid of the wind, and even against it, to make plates of steel and iron, and so build ships without wood; and the beginning of that change dates from the time when Symington fitted Watt's engine into the *Charlotte Dundas* in 1801.

It would be superfluous to point out that experiments and attempts had been made to apply the steam-engine to the propulsion of ships before Symington was finally successful in doing so. Experiments and attempts always precede a successful invention. But William Symington's applicaton of the steam-engine to propel the *Charlotte Dundas* was a momentous attempt, because it demonstrated that steam propulsion of vessels was not only possible but commercially practicable.

A section of the *Charlotte Dundas* we show on next page. Her length was 56 ft., beam 18 ft., and depth 8 ft. The engine was of 10 nominal h.p. It will be seen from the figure that the engine is horizontal, and transmits the motion of the piston to the paddle-wheel through a connecting-rod and a crank—the crank which was pirated from Watt and patented by some one else. The cylinder of the engine was 22 in. diameter, and had a stroke of 4 ft. The pressure of steam was probably about 5 lbs. per sq. in. above the atmosphere, but the engine was fitted with a condenser. When tried, the engine propelled the boat at a speed of six miles an hour, and when it acted as a tug it towed two barges, each of 70 tons burden, against a strong head wind through a reach of the canal 19½ miles in length in six hours.

This was the beginning of progress. We have now to indicate the lines along which progress has travelled. This will best be done by keeping clearly before the mind what existed at the beginning of the century, namely the *Charlotte Dundas*, and what we have in the present year in warships and in ships of commerce. Warships have developed in two directions—in power of resistance and speed, and in speed alone without resistance; and ships of commerce have developed in the directions of size and speed. Both developments began with the *Charlotte Dundas*, and they have reached the *Oceanic*, a mixed passenger and cargo ship, the *Deutschland*, a passenger liner, and with *Powerful* and *Viper* ships of war.

When a natural force like that of the expansive force of steam is utilised to do work, improvements in its application can go on in two directions. Given the bare application of steam to propel the *Charlotte Dundas*, it can be improved by (1) a better arrangement of mechanism, so that the reciprocating movement of the piston shall be best transmitted to the paddle-wheel or screw, under the exigencies of the case; (2) a better use of the fuel, so



MACHINERY OF THE "CHARLOTTE DUNDAS" (1803).

that the greatest possible work may be obtained from it. The first is the work of the draughtsman, the second that of the highly-trained engineer.

While we will be able to show that ship-building kept improving continuously all through the century, it will be best to divide the progress of marine engineering into two periods—the first 60 years of the century with low pressures of steam, direct expansion, and jet condensers; and the last 40 years with high pressures of steam, graded expansion, and the surface condenser.

The next successful practical application of the steam-engine to propel a ship was in the *Clermont*. She was a passenger steamer 133 ft. in length, 18 ft. breadth, 9 ft. in depth, and 160 tons burden. She was built at the yard of Charles Brown, on the East River, New York, in the spring of 1807. Robert Fulton made no pretensions of designing a special engine for her, as he simply fitted in a vertical Boulton and Watt engine, and designed the mechanism for transmitting its motion to the paddle-wheels. The *Clermont* had two side paddle-wheels fitted on a main shaft. The cylinders were 24 ins. in diameter, 4 ft. stroke, and the intermediate mechanism consisted of bell crank levers, which rotated an intermediate crank shaft. This latter was connected to the paddle shaft by gear wheels. The arrangement was not so simple as that of *Charlotte Dundas*, and the speed attained was rather less. The *Clermont* carried passengers between New York and Albany on the Hudson, and made the first journey of 150 miles in 32 hrs.; the return journey was done in 30 hrs., which gave an average speed of 5 miles an hour.

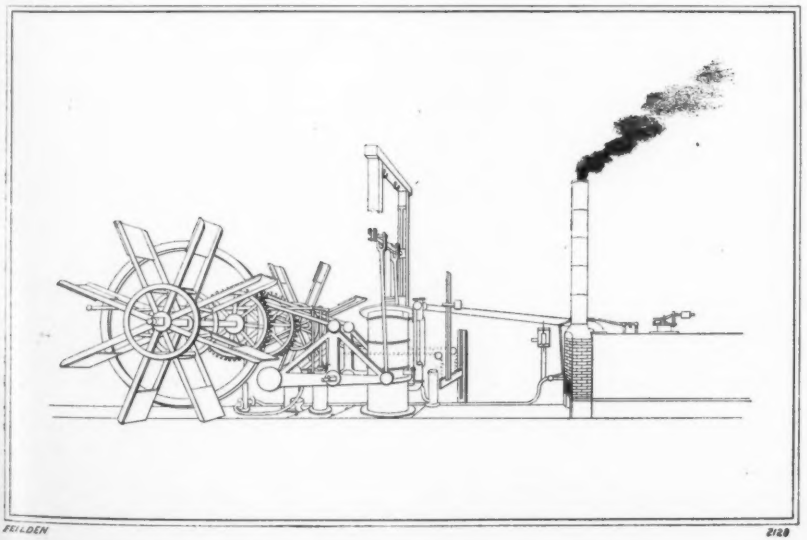
The *Comet* shows the next advance. She was built on the Clyde by Henry Bell in 1811. We give a figure of it as erected in the Victoria and Albert Museum, South Kensington. The *Comet* was 40 ft. long, 10½ ft. beam, and 30 tons burden. Her engine cylinder is vertical, placed on top of the crank shaft, and the connecting-rods move two levers which are connected under the cylinder by a shaft, and that drives the crank through a connecting-rod. The crank shaft is geared to two pairs of paddle-wheels, one at the front and another at the back.

The slide valve is driven from the main shaft through a rocking shaft. The condenser is between the levers. The speed was 5 knots an hour. She carried passengers between Glasgow, Greenock, and Helensburgh.

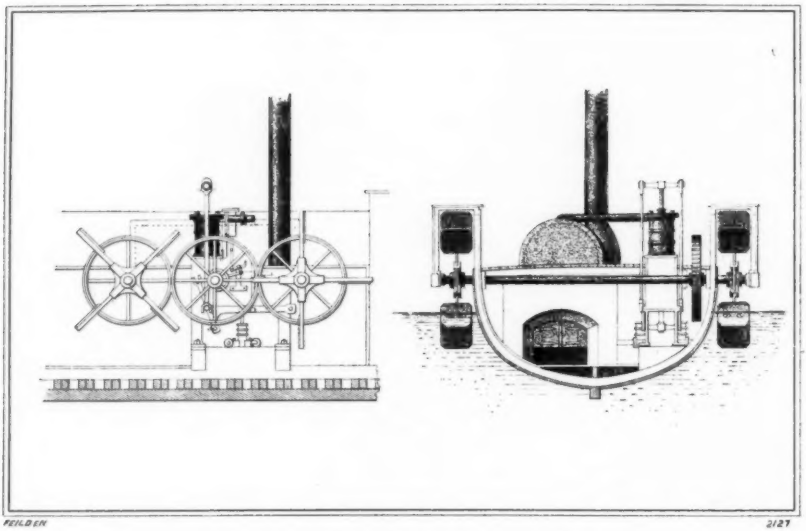
Messrs. Maudslay & Field, in 1815, began their long successful construction of side lever engines for paddle-steamers, when they fitted them in the *London Engineer*. The paddle-wheels were fitted inside a cut-out box like the *Charlotte Dundas*, but had bell-crank levers to transmit the motion between piston and crank shaft. She was 120 ft. in length, 24 ft. breadth, and 5 ft. draught; the paddle-wheels were 12 ft. 6 ins. diameter, and 6 ft. 6 ins. wide. Her cylinders were 36 ins. diameter, and 36 ins. stroke, and vertical. The air-pumps were worked by side rods attached to pins in the bell-cranks. The paddle-shaft made 28 revolutions per minute, and the steam, which was generated in three boilers of the ordinary flue type, had a pressure of 5 lbs. per sq. in.

It must not be imagined that these steamers referred to were experiments made by their builders. Steam shipbuilding was now in full swing. Fulton, we saw, had a fleet of steamers on the Hudson; while in our own country, as early as 1819, the tonnage of commercial steamers had reached 6,657. Up to this time, and for many years to come, progress was confined to the development of the mechanism of the marine engine. Improvement and change were slow. Even the side-lever engine is simply Watt's beam-engine with the beam placed at the side to save space, and is an adaptation of the same to marine purposes, as was Symington's direct-acting engine at an earlier date.

To economise space, Joseph Maudslay introduced the oscillating engine for marine purposes. The cylinders were placed under the paddle-wheel shaft, and made to rock on trunnions, obviating the necessity of a connecting-rod. They became great favourites for paddle-wheel steamers, and are still to be seen on the Thames to-day. As early as 1822, Aaron Manby had fitted an iron ship with an engine with oscillating cylinders. This



PERSPECTIVE VIEW OF MACHINERY IN FULTON'S "CLERMONT" (1807).



ENGINE AND PADDLE-WHEELS OF THE "COMET" (1812).

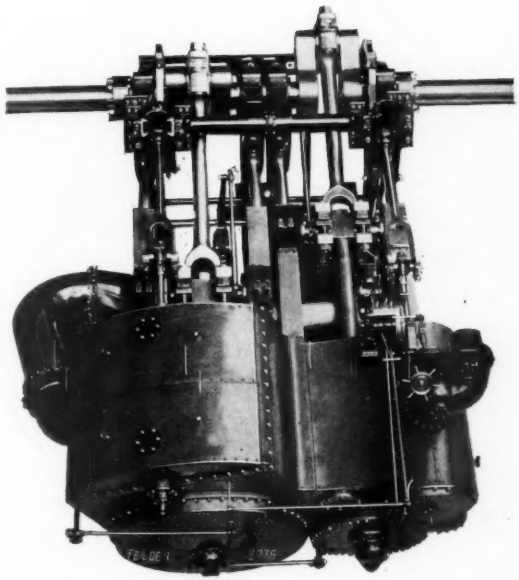
ship was 120 ft. long, 18 ft. beam, and $3\frac{1}{2}$ ft. draught, the engines being 80 h.p. She plied across the Channel, and was the first iron ship to make a sea voyage. A notable illustration of this type of engines is the set fitted into H.M. screw yacht *Fairy*, built by Mr. Hitchburn. The application of oscillation engines is shown through gear wheels to the propeller shaft, and if such wheels were removed the crank shaft would serve for the paddle shaft. The boat was 144 ft. 8 in. long, 21 ft. $1\frac{1}{2}$ in. broad, displacement 196 tons, draught 5 ft. 10 in. The engines were 364 i.h.p. when making 51·6 revolutions per minute, and her speed was 13·6 knots per hour. She had three flue-tube boilers of the box form, with a heating surface of 853·77 sq. ft. and the pressure of steam was 11 lbs. per sq. in.

As the oscillating engine was designed to obviate the necessity of the connecting-rod, so the trunk engine was made in order that the piston-rod could be eliminated. It was introduced by Messrs. Penn, of Greenwich, for the screw propulsion of warships in 1847, and, being below the water-line, was therefore safe from gunshots, and found great favour. With comparatively low pressures it worked well; but the extensive gland surfaces of the stuffing-boxes and exposure of the trunk surfaces to cooling were serious disadvantages with high pressures. The last large ship, H.M.S. *Neptune*, fitted with trunk engines in 1876 was 9,000 h.p.

Messrs. Humphrys and Tennant introduced the horizontal direct-acting engines in 1869. The vessel's length was 240 ft., beam 48 ft., depth 25 ft. 3 in., and draught 17·7 ft. The engines consisted of two cylinders 72 in. diameter, 3 ft. stroke, connecting-rods 63 in. long, which had forked ends with the pins fast in them. They were fitted with double-ported slide valves and arranged to cut off at two-thirds the stroke in full gear. The condenser was of the jet type, the sea-water entering by a long slotted pipe. There were two double-acting air pumps $22\frac{1}{2}$ in. diameter within the condenser, and two feed pumps $7\frac{5}{8}$ in. diameter, both driven direct from the piston. The engines developed 2,128 i.h.p. with steam at 24 lbs. pressure at 61 revolutions per

minute. The steam was supplied by four boilers of high rectangular type.

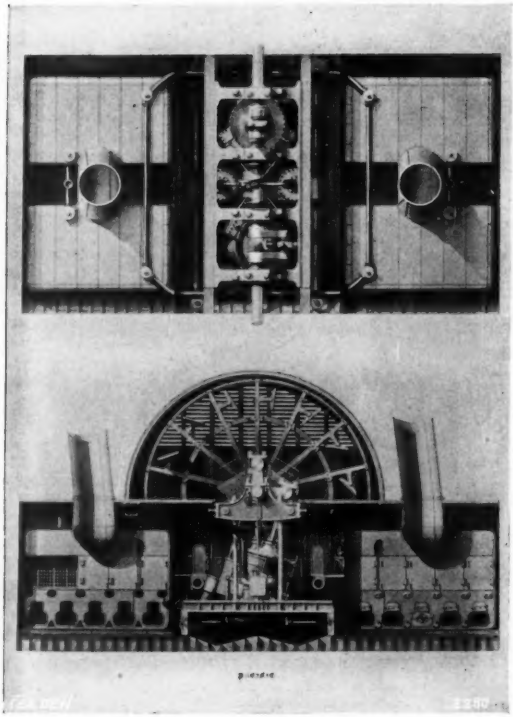
Two improvements in shipbuilding and ship propulsion, progressing independently, each in the experimental and trial stage, were preparing the way to make the industry advance by leaps and bounds. These improvements were the screw propeller, and iron as the building material. Mr. John Laird, in 1829, built a lighter 60 ft. long, 13 ft. 4 in. beam, and 6 ft. deep, and in 1833 a paddle-steamer, the *Lady Lansdown*, of 148 tons burden, 13 ft. long, 17 ft. broad, and 9 ft. 6 in. deep. It was soon seen that iron ships could be made of the same capacity as wooden ones, but of half the weight. Mr. Pettit Smith, a farmer at Hendon, and Captain J. Ericsson successfully and independently introduced the screw propeller to ships. Mr. Smith fitted a screw propeller on the *Archimedes*, a vessel of 238 tons burden, in 1838. She was engined by Messrs. G. & J. Rennie with a pair of engines with cylinders 37 in. diameter with 36 in. stoke, the revolutions being 26 per minute, and the propeller geared up to run at 138⅓ per minute. The propeller consisted of one complete revolution of the helix of a screw 5 ft. 9 in. diameter. The vessel made 9·25 knots. She was next fitted with a double-threaded screw, and tried against the *Widgeon* between Dover and Calais. She beat the *Widgeon* by 9 minutes, and on the return journey by 5½ minutes.



DIAGONAL COMPOUND ENGINES OF THE "PRINCESS HENRIETTA."

A third factor introduced at this time into the industry was due to the greater Brunel. This factor was the successful running of the *Great Western* between Bristol and New York. With regard to shipbuilding, perhaps Brunel held the soundest and most practical views of the century. They are embodied in the *Oceanic* of to-day, and he often pointed out that for a company to hold their own as shipowners they must have large ships and economical engines.

It was at a meeting of the directors of the Great Western Railway, in October, 1835, that a beginning was made. One of the directors had referred to the great length of the line between London and Bristol, when Brunel said, "Why not make it longer, and have a steamboat to go from Bristol to New York, and call it the *Great Western?*" The suggestion was discussed the same evening by Mr. Brunel and Mr. Guppy, and resulted in the formation of the Great Western Steamship Company, and in Mr. Paterson, of Bristol, building a wooden paddle-steamer, the *Great Western*, which was engined by Messrs. Maudslay and Field. Her length over all was 236 ft., beam 35 ft. 4 ins., draught laden 16 ft., and 1,340 tons burden. The engines were of the side-lever type; the paddles were 28 ft. diameter, with radial floats 10 ft. long. Her four boilers were of the box form with flues. Their length was 11 ft. 6 ins., width



ENGINES OF THE "PACIFIC."

Two cylinders 74 ins. diam., 7 ft. stroke, i.h.p. 1684, steam pressure 18 lbs., paddle wheels 27 ft. diam., speed, 14 knots; by Scott Russell.

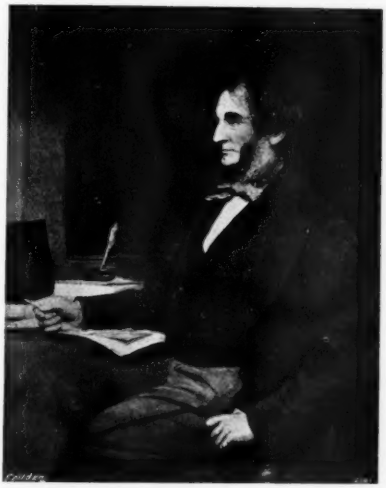
9 ft. 6 ins., and height 16 ft. 9 ins. The furnace surface was 890 sq. ft., flue surface 2,950 sq. ft., which gave a total heating surface of 3,840 sq. ft. The engines indicated 750 h.p., and the coal consumption was 30 tons per day, and pressure of steam 6 lbs. per sq. in.

While she was building at Bristol, the famous controversy arose in which Dr. Lardner proved that it was impossible for any vessel to carry sufficient coal to take her across the Atlantic. The British Association met at Bristol that year, and Dr. Lardner, like most critics, availed himself of the opportunity of doing the company all the damage he possibly could. His lecture was entitled "Transatlantic Steam Navigation," which was delivered on August 25th, not long after the building of the *Great Western* had begun. *The Times* reports him to have said, "Let them take a vessel 1,600 tons, provided with 400 h.p. The vessel must carry a burden of 1,748 tons. He thought it would be a waste of time under all the circumstances to say much more to convince them of the inexpediency of attempting a direct voyage to New York, for in this case 2,080 miles was the longest run a steamer could encounter; at the end of that distance she would require a relay of coals. . . . We have as an extreme limit of a steamer's practicable voyage without receiving a relay of coals a run of 2,000 miles." She sailed on April 8th, 1838, taking 850 tons of coal on board, and arrived at full speed in the afternoon of April 23rd, having made the passage in 15 days, and with 200 tons of coal left in her bunkers. She started on her return journey on May 7th, with 68 passengers on board, and made the voyage in fourteen days, although one day was lost by a stoppage at sea. After this she ran regularly until 1846. One account says she consumed 655 tons of coal on her first voyage out, and 392 tons on her return voyage. She made 64 voyages altogether, carrying an average of 85 passengers per voyage. Her fastest westward run was 12 days 18 hours, the fastest eastward was 12 days $7\frac{1}{2}$ hours.

The fact that a steamship had crossed the Atlantic influenced the minds of shipowners and men of commerce as the voyages and victories of the Elizabethan seamen affected the minds of men of that time A new world had been opened up to shipowners. In 1840 the transatlantic steam traffic was put on a firm foundation by three gentlemen, Mr. Samuel Cunard, of Novia Scotia, Mr. George Burns and Mr. David M'Iver, of Liverpool, when they

established the Cunard Company and their offer to carry the mails to America regularly for the English Government was accepted. They contracted to run a fleet of at least four vessels between Liverpool and New York, and establish a fortnightly service between the two countries. Their first four vessels, the *Acadia*, *Britannia*, *Columbia*, and *Caledonia*, were of the same type as the *Great Western*, and the engines were also like those of the *Great Western*, of the side-lever type with jet condensers. The contract was for seven years, and the mails were to be carried regularly between Liverpool, Halifax, and Boston for £81,000 per annum. The dimensions of the *Britannia* were: Length of keel and fore rake, 207 ft.; breadth of beam, 34 ft. 2 ins.; draught, 16 ft. 10 ins.; displacement, 2,050 tons; diameter of cylinders, 72½ ins.; stroke, 82 ins. She was fitted with four boilers of the return tube type, with steam pressure of 9 lbs. She indicated 740 h.p., and consumed 5·1 lbs. of coal per h.p. per hour, or 38 tons per day. Her bunker capacity was 640 tons of coal, cargo capacity 225 tons; she besides carried 90 passengers, and her average speed was 8·5 knots per hour. No claims of superiority were made for those vessels over the *Great Western*. The Peninsular and Oriental Company was founded in 1837, and it soon became the Peninsular and Oriental to India. After this the development and improvement of existing practice, stimulated by competition between the different shipping lines, sets in.

It has been pointed out that the Lairds were building ships with iron, and that Smith was making successful progress with the screw-propeller. Brunel decided to build for the Great Western Steamship Company a ship of iron which would have much greater cargo capacity. Although this vessel was laid down to be fitted with paddle-wheels, he strongly advised that the design should be changed in order that the screw-propeller should be adopted. His leading idea in the design was to have a large ship with great proportional cargo space; speed was not so important. The dimensions of this vessel, the *Great Britain*, were a decided advance on the *Great Western* and the *Britannia* of the Cunard Company. Those dimensions were: length 322 ft., beam 51 ft., depth 32 ft., and displacement 2,944 tons, by measurement 3,443 tons. She had four cylinders, 88 ins. diameter, 6 ft. stroke, and they were set diagonally, their axes being inclined 33 degs. to the vertical, between two athwart ship frames. The crank-shaft was supported on **A** frames made of wood and covered with iron plating. A drum was fixed to the middle of the shaft, and a similar drum opposite to it was fixed on the screw shaft: the two were connected by four flat pitch chains; the crank-shaft drum was 18 ft. 2 ins. diameter, and had teak blocks fitted in it to engage the chains; the other drum had lignum vitæ blocks. These made the working almost noiseless. The condensers were of wrought iron, 12 ft. long, 8 ft. wide, and 5 ft. deep. They were placed between the cylinders, and the air-pumps worked in them were actuated from the main crank shaft. The feed and bilge pumps were actuated by a lever worked from the cross-head of the air-pump. The propeller shafting was in three lengths; that at the engines was



JOHN LAIRD, WHO INTRODUCED IRON AS A SHIPBUILDING MATERIAL.

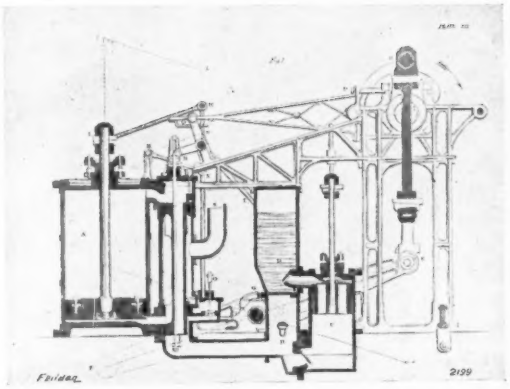
28 ft. 3 ins. long and 16 ins. diameter in the journals; the middle shaft was 61 ft. 8 ins. long and 30 ins. diameter, and made of two thicknesses of $\frac{3}{4}$-in. plates bent and riveted together with $1\frac{3}{8}$-in. counter-sunk rivets; the length attached to the propeller was solid, 18 ins. diameter and 25 ft. 6 ins. long. The water was kept out of the ship by leather packing in the stern post, kept in place by a gland. The thrust was taken up by a steel disc and a gun-metal disc pinned to a collar on the shaft. The screw-propeller was of wrought iron with six arms, with inclined plates riveted to the ends 2 ft. 10 ins. deep and $\frac{7}{8}$ in. thick, while the diameter was 15 ft. 6 ins. and the pitch 25 ft. The planes were planed, painted, and varnished to reduce the friction. The ship had a balanced rudder. The boilers were three in number, but they consisted of one outside shell, 34 ft. long, 31 ft. wide, and 21 ft. high, which was divided internally into three distinct boilers with four furnaces at each end. A jacket was formed round the base of the uptake to heat the feed water. There were 360 sq. ft. of grate surface, 1,248 sq. ft. of heating surface in furnaces, with a total flue surface of 9,852 sq. ft. The sides of the ship between the boiler-room bulkheads were used as bunkers, and contained 1,000 tons of coal. The boiler-room took up 50 ft. of length of the ship and the engine-room 30 ft. She made 9 knots on trial, but her average speed was 9·25 knots, and the engines indicated 600 h.p.

ISAMBARD KINGDOM BRUNEL.

The stern frame was a single forging, 15 ft. deep, 3 ft. wide at lower end, and 12 ft. at upper. The ribs were angle iron, 6 ins. by $3\frac{1}{2}$ ins. by $\frac{5}{8}$ in., spaced 18 ins. apart amidships and 24 ins. at ends. The outside plates were from 6 ft. to 6 ft. 6 ins. long, 3 ft. wide, and rather over $\frac{5}{8}$ in. thick, at the end $\frac{3}{8}$ in. thick. Two bilge keels, 110 ft. long, were fitted to prevent her rolling. The deck beams were of angle iron, 6 ins. by $3\frac{1}{2}$ ins. by $\frac{1}{2}$ in., the ends being bent down and riveted to the ship's sides. The upper deck was supported by wooden pillars secured at their lower ends to the cargo deck. She was the first iron ship of considerable size, and the first screw steamer, to cross the Atlantic.

Later Brunel designed the *Great Eastern*, and the matter is only mentioned here to show the direction in which he worked. She was 650 ft. long, 82 ft. 6 ins. broad, and 58 ft. deep; her displacement was 27,384 tons. She was engined as a paddle steamer and also as a screw steamer. The screw engines indicated 4,886 h.p. There were four steam cylinders, each 48 ins. diameter by 48 ins. stroke, driving two cranks at right angles. The shaft made $38\frac{3}{4}$ revolutions per minute. The propeller was a four-bladed iron screw, 24 ft. diameter, 44 ft. pitch. The paddle engines were oscillating and had four cylinders 24 ins. diameter, 14 ft. stroke, the revolutions being $10\frac{3}{4}$ per minute. The cylinders were inclined at a mean angle of $22\frac{1}{2}$ degrees from the vertical, and two drove one crank, while the other two drove another at right angles to the first. She indicated 3,411 h.p., with 24 lbs. of

steam pressure. The total horse-power was thus 8,297. The boilers were of the box type. She was supposed to go at 15 knots an hour with paddles and screw working. She made 7¼ knots with paddles alone and 9 knots with the screw. She was to carry 800 first-class passengers, 2,000 second-class, and 1,200 third-class; as a troop-ship, 10,000 men. Her average speed across the Atlantic was 14 knots, and coal consumption 14·5 tons per hour, making the voyage in about 9½ days. Had there been sufficient work for her she ought to have paid well enough, but trade had not reached the stage of employing so large a steamer. At the above rate she would have gone to the Cape in 18 days and consumed 6,235 tons of coal.

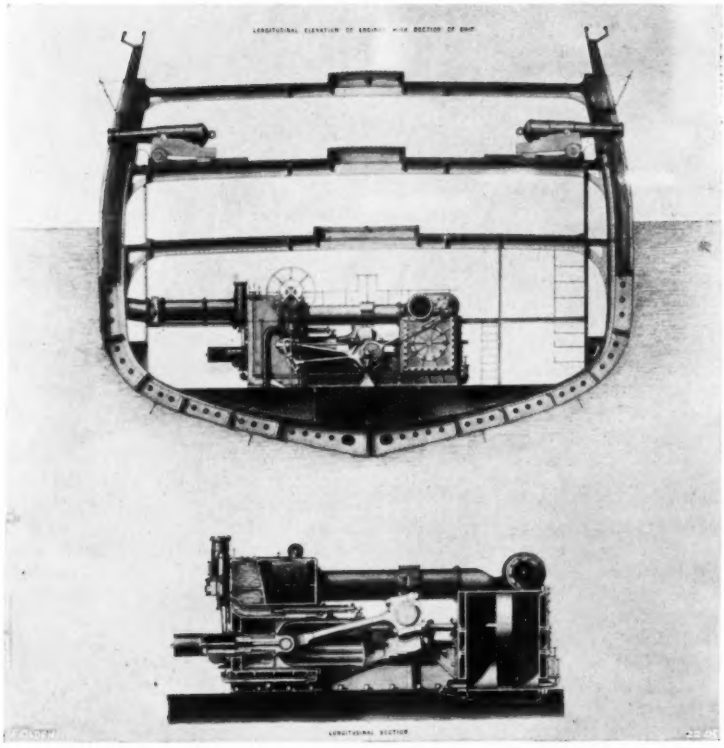


AN EXAMPLE OF A SIDE LEVER ENGINE.

The Admiralty after this gradually adopted the screw-propeller, but at first it was arranged that means should be provided for shipping and unshipping the propeller, so that vessels could be efficiently worked as sailing ships although fitted with screws. About 1845 all the eminent engineers were called upon to offer designs of engines specially adapted to drive the propeller shafts under Admiralty conditions supplied them. The result was that most of the eminent manufacturing engineers were given an opportunity of carrying out at least one of the plans which they had submitted. It was clear that those would be most in favour which dispensed with gearing and the noise which resulted from its use.

Those submitted by Messrs. John Penn & Sons were for engines of the double trunk type. They were horizontal, the cylinders being on one side of the crank shaft and the air-pumps and condenser on the other side. The connecting-rod was attached at one end to the middle of the trunk and at the other end to the crank pin. The pumps were double-acting, and were worked by rods attached to the steam pistons and passing through stuffing-boxes in the cylinder covers. The feed and bilge pumps were worked in the same way. The crank shafts were balanced. The boilers were of the tubular type, the tubes being on the same level as the fire-boxes, so that

SAMUEL CUNARD.



ENGINES OF H.M.S. "HECTOR." RETURN CONNECTING ROD TYPE.
(Reproduced by permission of the Council of the Institution of Mechanical Engineers.)

everything might be kept low and under the water-line of the vessel. The pressure of steam was about 6 lbs. per sq. in.

Messrs. Rennie, about 1853, fitted into an Australian mail steamer, the *Crœsus*, a set of engines which ultimately were adopted for war-ships for very much the same reasons as Penn's trunk engines, but they have advantages which Penn's do not show. The General Screw Steamship Company proposed, in 1851, to a Committee of the House of Commons to run to Australia by the Cape route screw steamers of 1,400 to 1,700 tons, with engines of 300 h.p., which would steam at the rate of about 8½ knots an hour, and make the outward journey in 64 days and the homeward one in 68 days. The *Crœsus* was one of the vessels built for this purpose. She was an iron frigate-built screw steamship, 280 ft. long between perpendiculars, 43 ft. beam, 33 ft. 6 ins. depth of hold, and 2,500 tons burden. She carried canvas enough to make 13 to 14 knots with a stiff breeze. Her passenger accommodation was large, and she had a cargo space for 1,300 to 1,400 tons and 1,000 tons of coal, also tanks for 113 tons of fresh water and apparatus for condensing 700 gallons per day.

Her engines, made by Messrs. Rennie, consisted of two cylinders each 63¼ ins.

diameter, with 2 ft. 9 ins. stroke, and were situated on one side of the crank shaft, while the condensers were on the other. The piston-rods are seen to be long, driving a crosshead to which is attached the connecting-rod, the other end of which returns to the shaft which rotates between the two piston-rods. The slide-valves were double-ported and worked with double eccentrics and slotted links. It had a surface-condenser, the cooling water was drawn through the tubes, and arrangements existed for turning it into a jet condenser if necessary. The air and circulating pumps were drawn from the outside piston-rods. The boilers were of the box form, had 7,500 square feet of heating surface; the pressure was 20 lbs. per sq. in.

Here, it will be observed, the surface-condenser and evaporator are introduced, and it is made possible to use high-pressure steam, but the boiler for doing so had not been provided. The surface-condenser used in this case was not of the prevalent form adopted now. The tubes were vertical and the steam circulated through them; the water, as mentioned above, was drawn through amongst the tubes.

This was by no means the first of surface-condensers. Watt designed one, but nothing came of it. He was not pushed to develop it, since he did not take up the question of marine engineering. David Napier made a successful one about 1820-21, and he made others later; but the necessity for them had not then become urgent, pressures and temperatures being so low. Engineers did not care for them. Mr. S. Hall made successful condensers, and fitted one in the paddle-wheel steamer *Wilberforce*. In 1845, H.M.S. *Grappler* was fitted with one, and after three years the boilers and condensers were found in good condition. Mr. Humphrys fitted one in the P. & O. steamer *Mooltan*, and after it had steamed 30,000 miles the boilers and condenser were in excellent condition, but the urgent necessity for them had not arrived.

Higher pressures of steam were at last called for by the necessity for a greater economy in coal. The long voyages which were multiplying during the fifties caused a demand to be made for engines of higher economy. The Pacific Steam Navigation Company began the new departure, by ordering two paddle-wheel boats, the *Valparaiso* and the *Nica*, from John Elder & Co., to be fitted with compound engines using steam of 25 lbs. pressure. The engines had four cylinders, two high-pressure, 50 ins. diameter, and two low-pressure of 90 ins. diameter, steam jacketed top and bottom. The cylinders were arranged in pairs, each pair inclined to each other. Two high-pressures worked on one crank, and the two low-pressures on the other. The cranks were opposite each other, and not at right angles, but as the cylinders were inclined there was no dead centre. The engines indicated about 900 h.p., the piston speed was from 230 to 250 ft. per minute. The engines worked well, and the company ordered that all other boats in the service should be so fitted. The next set of engines was built, and the cylinders jacketed all over, with the result that a great deal of cylinder condensation was prevented, and a rise in indicated horse-power to 1,150 was the result.

In 1860, Messrs. Randolph, Elder & Co. introduced surface condensers and raised the steam pressure to 40 lbs. Probably they at this time began to use Scotch cylindrical boilers, but the cylinders of the engines were still kept about the same, and the higher pressure resulted in a development of 1,450 i.h.p. A slight change was made in the cylinders of the *Arequipa*, they being made 38 ins. and 78 ins., and working with steam pressure of 60 lbs. But though the engines were smaller, the power indicated rose to 1,720 h.p., and the fuel consumed was only half that required for the original *Valparaiso* engines. About the same time other attempts were made. The *Thetis* was built by Mr. John Scott, of Greenock, and fitted with compound engines by Messrs. Rowan. Water-tube boilers were used, and they worked well for a time. When tried by Professor Rankine the consumption of coal was 1·018 lbs. per i.h.p. At sea the consumption was 1·86 lbs. per i.h.p. Leakage and other troubles set in

with the boilers, and they had to be replaced by the ordinary cylindrical type.

Others had experimented with a new type of compound engine, in which the cranks were at right angles, and in which the steam had first to expand from the high-pressure cylinder into a receiver. Randolph & Elder also took this type up and improved it. In the Woolf engine the steam filled the high-pressure cylinder every stroke. This new type was arranged so that the steam could be cut off at any part of the stroke in the high-pressure cylinder, and allowed to expand during the remainder of the stroke. The steam exhausts into a receiver from the high-pressure cylinder, and is then admitted to the low-pressure cylinder, and is there cut off at any point of the stroke and allowed to expand.

With the crank shaft now low in the hull of the boat to suit the propeller shaft in line with it, designers of engines gradually worked round into the inverted type. With the Woolf compound, inclined engines had to be used; with the receiver type this was unnecessary, and the cylinders soon were made of one casting. Before that, however, there were cylinders of the direct-acting kind and of the inverted type working with surface-condensers. A good example is the pair of direct-acting engines fitted by John F. Spencer into the *City of Cork*, one of the Inman line of steamships. The condenser is between the two engines, and assisted to support the cylinders. She was engined in 1862, and only consumed 2 lbs. of coal per i.h.p. per hour.

The screw propeller of the *Great Britain*, it will be remembered, was of the fan shape, the blades being on the ends of the arms. It was found that those arms churned the water, and threw it off, disturbing that which was in the way of the blades. The flapping action also caused waste of power. The central part was then filled up by a sphere, which absorbed hardly any of the power with its motion. The water at the blades was also left still. Griffiths also made improvements, and reduced the width of the blade towards the tips, as the velocity there was greater, and the width at the boss was made about equal to the diameter of the boss. This effected a saving of about 20 per cent. of the waste action, and the speed could then be reduced about one-third. A number of minor improvements were made to facilitate the means of securing the blades to the boss. Feathering screws were also introduced, but they were apt to go wrong.

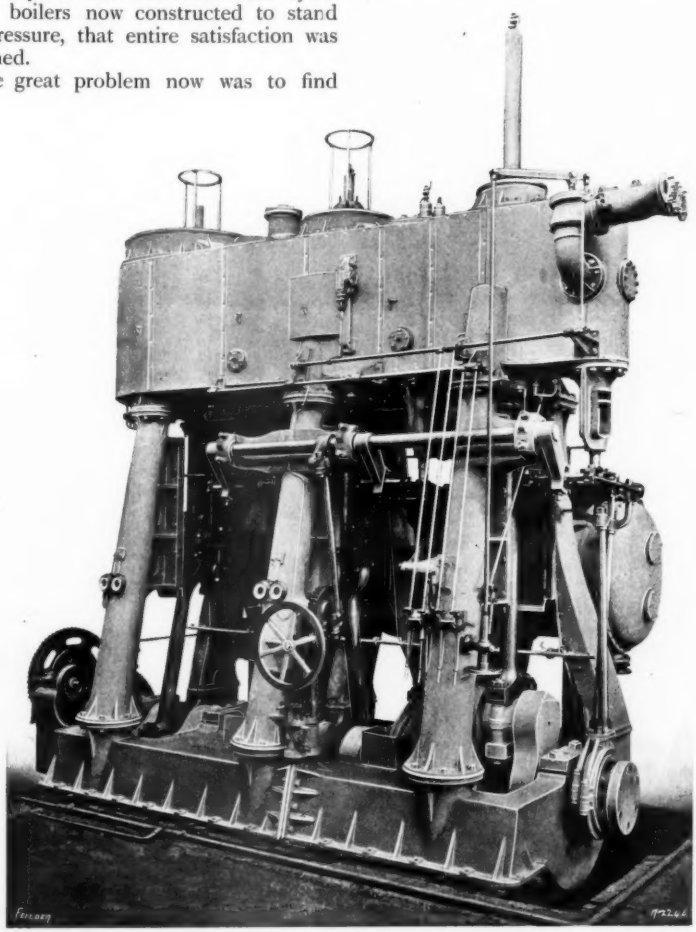
As pressures rose in the use of the compound engine by the improvements in the manufacture of steam boilers, it became a question of importance to distribute the work as evenly as possible round the crank shaft. This was partially accomplished in a set of engines fitted in the *Orient* by John Elder & Co. The *Orient* is 405 ft. long, 46 ft. 3 ins. beam, and 36 ft. 10 ins. deep, with a displacement of 9,500 tons. The engines have three cylinders, one high-pressure, 60 ins. diameter, and two low-pressure, each 85 ins. diameter, working on three separate cranks placed at 120 degs. to each other. The valves are of the piston type, arranged in a chest at the back, and are worked by link-motion reversing gears from the crank shaft. Two levers actuated by the low-pressure cross-heads drive the air circulating and feed pumps at the back. The steam pressure is 75 lbs., and i.h.p. 5,400.

In the Inman line another arrangement is adopted. These engines are tandem, in which the high-pressure cylinder is fixed above the low-pressure one, and the two pistons have a common piston-rod. The *City of Rome* has three such pairs, driving three cranks. These engines indicate 8,000 i.h.p. Mr. Alfred Holt simplifies the matter by using only one pair of tandem engines and a fly-wheel. The engine drives a crank-pin at the end of the shaft, and the expensive crank shaft forging is dispensed with.

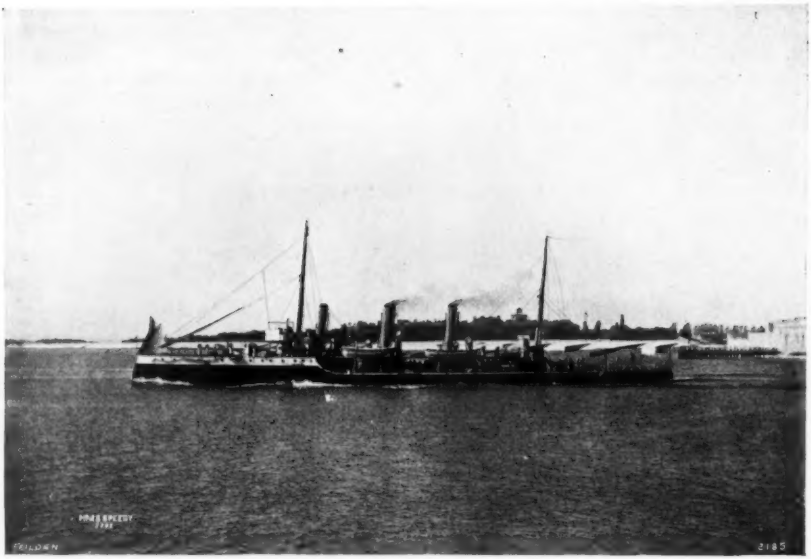
The demand for higher economy still grew. Mr. W. H. Dixon, a shipowner of Hull, placed an order with John Elder & Co. to construct the *Propontis*, the engines of which were to work at 150 lbs. pressure. Iron was still the material for boilers, and some diffidence was felt in constructing the ordinary type to stand this pressure in those days, and so it was decided to fit Messrs. Rowan & Horton's water-tube boilers in the ship. The great range of

temperature of the steam allowed Dr. Kirk to distribute it in three cylinders, and so introduced the triple-expansion type of engine. The cylinder diameters were 23 ins., 41½ ins., and 62⅛ ins., with a stroke of 42 ins. The type of engine was the inverted surface condensing, and they worked with great satisfaction. But the boilers gave way, and it was not until in later years she was fitted with cylindrical boilers now constructed to stand the pressure, that entire satisfaction was obtained.

The great problem now was to find material of sufficient strength to stand the high pressures of steam. About this time further improvements in the manufacture of mild steel allowed this material to be used for boilers, and with this improvement also must be mentioned the introduction of the corrugated furnace of Mr. Samson Fox. Riveting processes were improved, and it was soon possible



AN EXAMPLE OF THE LATEST TYPE OF TRIPLE-EXPANSION ENGINES, BUILT BY SIR CHRISTOPHER FURNESS, WESTGARTH AND CO., LTD.

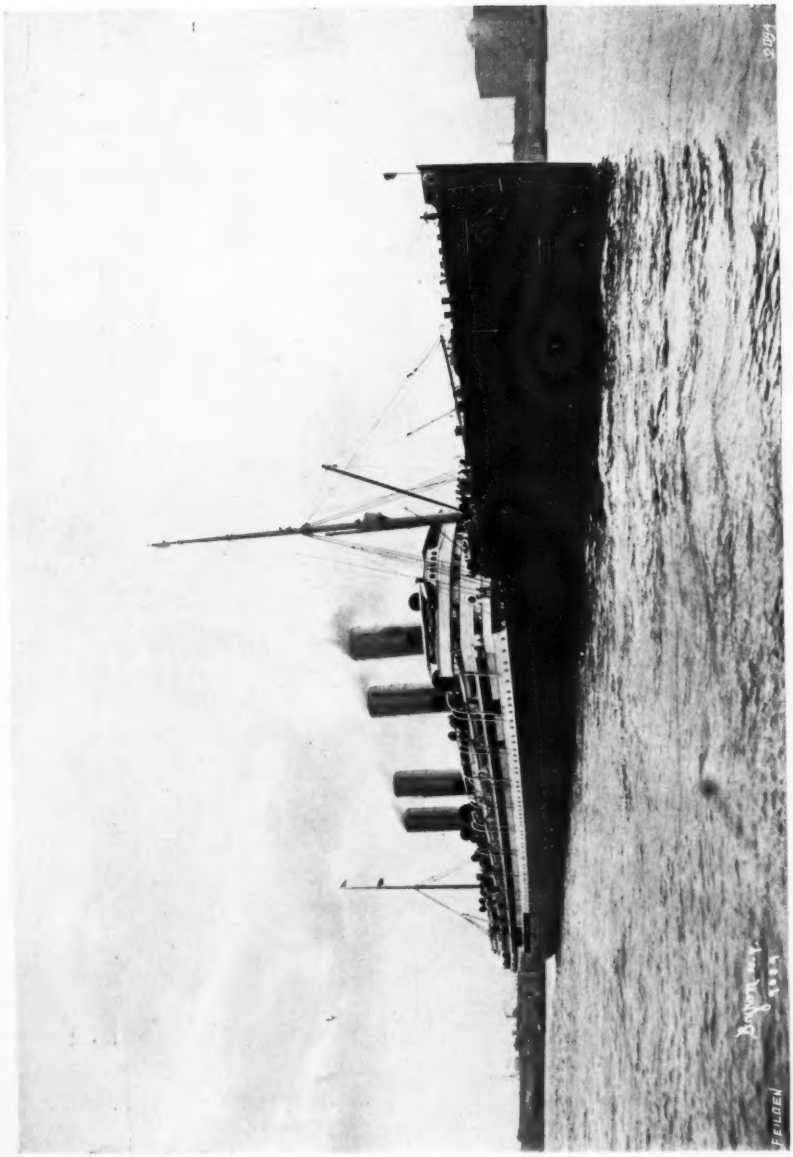


H.M.S. "SPEEDY." BUILT BY MESSRS. THORNYCROFT AND CO., LTD., AND FITTED WITH EXPRESS WATER-TUBE BOILERS.

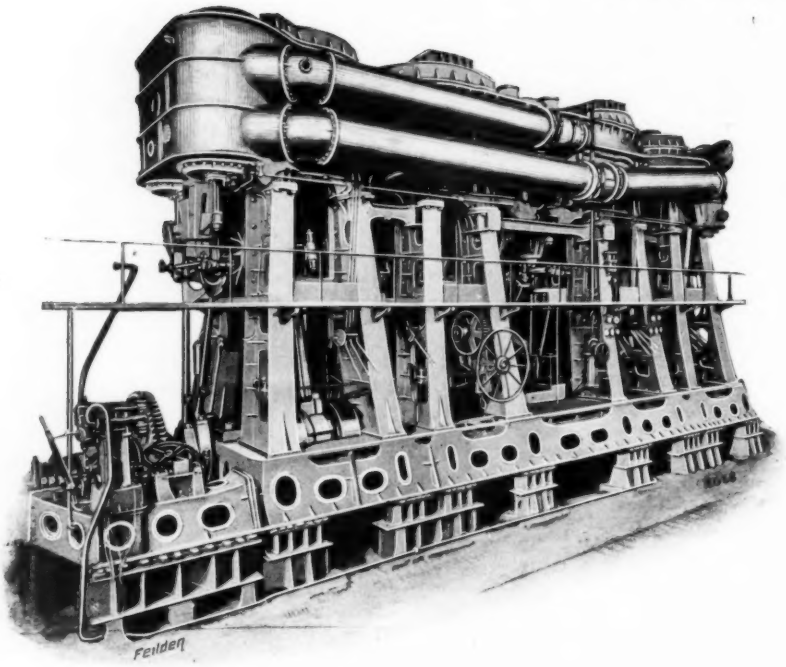
to construct boilers which stood pressures of 160 lbs. of steam. Messrs. G. Thompson & Co., of London, were the first to take advantage of these improvements, and had built for them the *City of Aberdeen* by Messrs. R. Napier & Sons. Her engines, designed by Dr. Kirk, were of the inverted type and triple expansion, with cylinders 30 ins., 45 ins., and 70 ins., and 4 ft. 6 ins. stroke. The high-pressure cylinders had no jacket, the intermediate was jacketed with steam of 50 lbs., and low-pressure cylinder with steam of 15 lbs. The consumption of coal was 1·28 when she indicated 1,800 i.h.p. The *Aberdeen* is 350 ft. long, 44 ft. beam, and 33 ft. deep; steam pressure 125 lbs. from two boilers, double ended of steel, with 6 Fox's corrugated furnaces in each, the heating surface being 7,128 sq. ft. In the discussion which took place when the paper which described her performance was read before the Institution of Naval Architects, Mr. John Scott, who originally tried the compound engine, said, "That system was abandoned at that time simply from the failure of the boiler, and not because we were disappointed with the result of the engines. Nobody, until Mr. Kirk led the way with this boiler as fitted to the *Aberdeen*, has had the courage to use steam of 125 lbs. at sea in a boiler of ordinary marine type."

There have been many different forms in which the triple-expansion engines have been arranged; the *Campania* and *Lucania* of the Cunard Line have them in sets of five cylinders working on three cranks. In the middle is the intermediate cylinder of 79 ins. diameter, on each side of that is a low-pressure cylinder of 98 ins. diameter, and above each of these, and working tandem with them, is a cylinder 37 ins. diameter. The stroke is 69 ins., the boiler pressure 165 lbs., and the piston speed 805 ft. per minute, each set indicating 14,000 i.h.p.

Improvements in auxiliary engines began to be made. The *Aberdeen* had a Weir's feed-water heater, and allowance had to be made for the steam taken away from the low-pressure receiver. The Australian



S.S. "DEUTSCHLAND."
FITTED WITH ENGINES OF 37,000 I.H.P. AND MAKING AN AVERAGE OF 23·36 KNOTS AN HOUR.



SET OF ENGINES OF THE S.S. "DEUTSCHLAND."

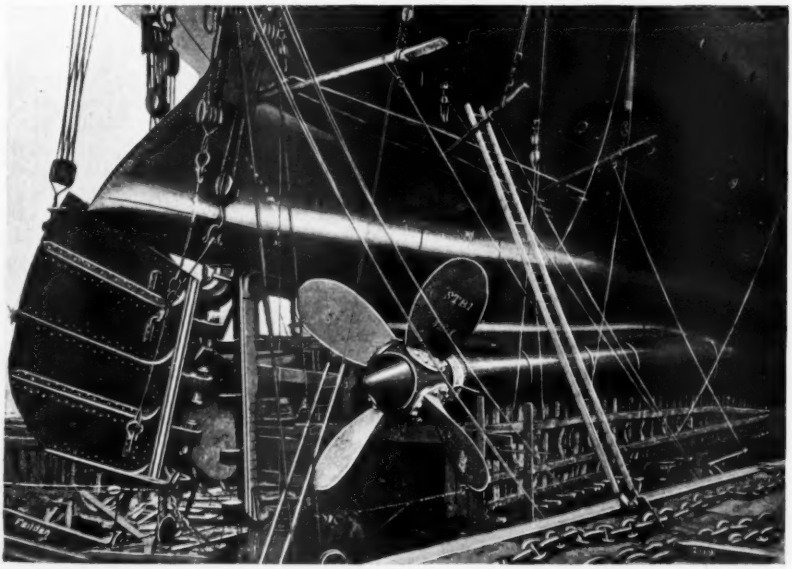
Cræsus also had evaporators with which to supply its boilers with fresh water. It early became evident as pressures rose that the salt would require to be got rid of from the water supplied to the boilers, and that which had been evaporated from sea-water was supplied. The leakage out of the system when surface-condensers are used is very considerable, and an allowance of six tons must be made for every 1,000 h.p. for 24 hours. Evaporators had thus to be supplied which would make six tons of fresh water every 24 hours per 1,000 h.p., to make up the loss. Storage tanks for holding this water were also a necessity. The use of fresh water for boilers was a great advantage to them, since it prevented the injurious deposit of salts on the heating surfaces and the obstruction to the transmission of heat and the risk of burning the plates.

Again, the oil used for lubrication was a great trouble, since it went into the condenser with the steam and so into the boiler, where it was liable to be deposited on the heating surfaces. Furnace crowns have often come down in consequence of an oil deposit being on them, because the oil offers a very great resistance to the heat getting through to the water, and consequently a great rise of temperature of the plate follows, when it loses its strength of resistance and comes down. Filters of charcoal, of towelling, etc., were introduced to prevent oil and salts getting into the boiler.

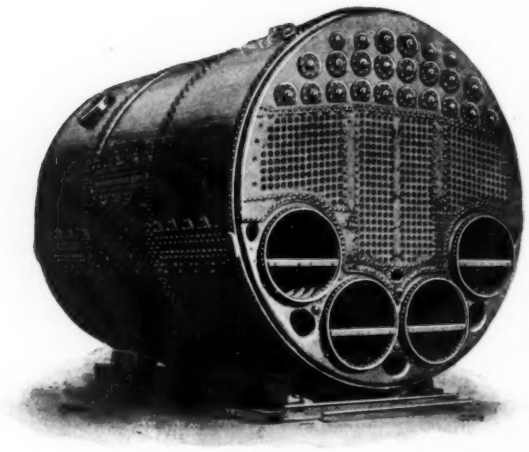
Then came attempts to increase the efficiency of evaporation of the boiler. Filters and evaporators were put in to prevent troubles, and by doing so increase the evaporation. But the feed-water heater was now introduced to raise the efficiency still

higher. Weir used exhaust steam and steam from the low-pressure receiver. After that came the feed-water heater, in which live steam was used. The classical experiments proving its efficiency were carried out on board the paddle-steamer *Oriol*, on the Thames. Exact measure of the increased evaporation from the use of live steam from the boiler has not been made, but whenever one of them is used it is claimed that it is followed by easier work for the stoker, a rise in pressure, and an increased number of revolutions made by the engines. Some claim that coal is saved when the number of revolutions is kept the same without the heater as before it. The reason is generally accepted that the cause of the higher efficiency is in consequence of the hot water supplied to the boiler improving the circulation, and by so doing increasing the absorption of heat by the water in the boiler. We have now brought the engine into the inverted form and triple-expansion type; the boiler we have brought to the cylindrical form, with its auxiliaries, the evaporator, the filter, and the feed-water heater.

In 1876 Messrs. J. I. Thornycroft built a small boat, 58 ft. long by 7 ft. 6 ins., of steel for the Norwegian Government, the object of which was to run rapidly in towards a ship of the enemy's fleet and discharge a torpedo at it. It was not protected, but depended entirely on its speed for its own safety. The British Admiralty began to build vessels on the same lines when they put down the *Lightning*, 81 ft. long, 10 ft. 10 ins. beam, and $32\frac{1}{2}$ tons displacement. Messrs. Thornycroft then laid down in 1880 a torpedo-boat for the Italian Government of still larger dimensions: 100 ft. long, 11 ft. 8 ins. beam, and $34\frac{1}{2}$ tons. These increased dimensions, of course, were for the purpose of increasing the speed. Then came 25 torpedo-boats for the British Government, 125 ft. long, 12 ft. 6 ins. beam, and $62\frac{1}{2}$ tons displacement. Then the Government of Brazil had one of 150 ft. long, 14 ft. 6 ins. beam, and $103\frac{1}{3}$ tons displacement, to make 25 knots; while



VIEW OF STERN OF S.S. "DEUTSCHLAND," SHOWING DETAILS OF RUDDER AND PROPELLERS.



RETURN TUBE CYLINDRICAL BOILER OF THE S.S. "DEUTSCHLAND."

following this came the British Government with another set 140 ft. long, 15 ft. 6 ins. beam, and 125 tons, to make 23½ knots. Nets and other things were put forward to protect a ship against torpedoes, but soon came the torpedo-boat destroyer, or catcher, of larger dimensions and greater speed than the torpedo-boat. These began with dimensions 185 ft. long, 19 ft. beam, and 220 tons, with a speed of 27 knots. These are intended to keep at sea, and are provided with a 24-ft. whale boat, two 20-ft. Berthon boats and a dingy. They have twin screws and are fitted with three-bladed propellers, which consist of steel forged blades keyed into steel bosses of the torpedo type. They carry three quick-firing guns, one a 12-pounder Hotchkiss on the top of the conning-tower, and two 6-pounder guns abaft the turtle back forward. A torpedo-tube is built into the hull forward, and a double torpedo gun on a turntable aft. Rails are run along the deck for carrying torpedoes from the conning-tower to the turntable. The boat's crew consists of about 40 men. The conning-tower is formed of ½-in. steel plate. The locomotive type of boilers was at first the favourite for this kind of craft. The engines had cylinders 18 ins., 26 ins., and 39½ ins. diameter, stroke 18 ins., and working with steam at 180 lbs. pressure. One of the boats, the *Hornet*, was fitted with eight Yarrow water-tube boilers. The reason given for building them so heavy was to provide them against falling off in speed when in a heavy sea, and they came up to expectations, for when a 30-mile wind was blowing, the speed made by the *Havoc* with 3,400 i.h.p. was 26·783 knots over the measured mile.

Another kind of craft of this type, but of still larger dimensions, designed to fight in line with warships is the torpedo gunboat cruiser. It is intended that she shall run into the enemy's line and pick off the cripples or fight the small craft. They are used also as scouts and despatch boats. The first of these was built at Laird's, and named the *Rattlesnake*. She is 200 ft. long, 23 ft. beam, and 8 ft. draught, with a displacement of 550 tons; the engines indicate 2,700 h.p., and her speed is 18·5 knots; she was armed with one 4-in. gun and six 3-pounder quick-firers. She had also four torpedo tubes, two fixed and two launching carriages. On trial with 136 lbs. of steam, she developed 2,718 i.h.p., and her mean speed at 310 revolutions was 18·779 knots. With a consumption trial at 11 knots and 373 i.h.p., she consumed 2 lbs. of coal per i.h.p., per hour, her radius of action being 2,800 miles. On trial in the manœuvres they were difficult to steer because of their light draught, and the *Sharpshooter* class was then designed. The *Rattlesnake* was 550 tons, but the *Sharpshooter* was made 735 tons, 230 ft. long, 27 ft. beam, depth 15 ft., and 8 ft. 3 ins. draught. She carried two 4·7-in. guns and four 3-pounders, and, like the *Rattlesnake*, carried four tubes. She developed 3,500 i.h.p., and made a speed of 20 knots.

The *Jason* class came next. Their displacement is 810 tons, with 8 ft. 9 ins. draught, their other dimensions being the same as the *Sharpshooter's*. They were armed with two 4·7-in. guns, four 3-pounders, and had three tubes. Of this class is the *Speedy*. Messrs. Thornycroft offered to take the risk of putting in their water-tube boilers, and promised that they would develop 1,000 more horse-power with the same space, and their offer was accepted. The machinery space is divided by bulkheads, there being two boiler-rooms and two engine-rooms. She is twin-screw, and the engines are 22 ins., 34 ins., and 51 ins. diameter, and 21 ins. stroke, and are the same as the *Jason* class; the revolutions were to be 250, and pressure 210. The air-pumps are 18 ins. diameter and $8\frac{3}{4}$ ins. stroke. The high-pressure cylinders had piston valves, and the intermediate and low-pressure are flat and balanced. The cylinders are not jacketed. The steam reversing gear is arranged so as to keep the engines going each way a few turns when the ship has stopped, which keeps the cylinders warm and the vacuum good. The slipper guides are forged steel with water-channels. The shaft is of compressed steel, and hollow. The condensers are of the cylindrical type, and brass. The *Speedy* has four water-tube boilers in each hold, each with 1,840 sq. ft. of heating surface. The total heating surface of the *Jason* is 6,388 sq. ft., that of the *Speedy* 14,720 sq. ft. The boilers were built in after the deck had been completed. Two Weirs feed-pumps maintain the feed. The *Hebe*, one of this class with loco-boilers, on trial made 17·8 knots with natural draught when developing 2,702·5 h.p., and 19 knots when developing 3,566·2 under forced draught. The *Speedy* made 18·5 knots when developing 3,046 i.h.p. with natural draught, and 20 knots when developing 4,674·4 i.h.p. under forced draught. She easily made 1,000 h.p.

THE DINING SALOON OF THE S.S. "DEUTSCHLAND."

over the others with the same machinery space.

After the success of the *Speedy*, water-tube boilers of the small tube type were fitted in all torpedo craft, and even sloops and 2nd-class cruisers, and the speed of these is still increasing. The British Government have now 30- and 31-knot destroyers, as have also the Japanese Government. The latest is the *Viper*, constructed by the Wallsend Shipbuilding Company, and engined by the Parsons Engine Company with steam turbines. It was to have made a speed of at least 31 knots; on trial it made 36 knots.

We have already drawn attention to the fact that Brunel believed that steamship economy lay in the direction of large ships and moderate speeds, and he had built the *Great Eastern*, which made 14 knots. Had there been sufficient traffic to be carried across the Atlantic, it might have been successful even then. Builders had to keep to small ships and gradually work up their dimensions with the increase of traffic. It is only now that a large ship would pay on the Atlantic line, but the traffic is not yet heavy enough to employ them on any other. In 1874 Harland & Wolff built the *Britannic*, 445 ft., 45 ft., and 36 ft., with a displacement of 8,500 tons. In 1881 came the *City of Rome*, 542 ft. 6 ins., 52 ft., and 38 ft. 9 ins., with 11,230 tons. In 1890 came the *Teutonic*, 565 ft., 57 ft. 6 ins., and 42 ft. 2 ins., with 22,000 tons; and now in 1899 Harland & Wolff build one 5 ft. longer than the *Great Eastern* and of 1,500 tons greater. The moulded dimensions of the *Oceanic* are 685 ft. length, 68 ft. beam, and 48 ft. deep, with 32 ft. 6 ins. draught and 28,500 tons displacement. She is 15 ft. narrower than the *Great Eastern*. The hull weight is probably 11,000 tons, the displacement, 28,500 tons, these being at load draught. She is fitted for 410 first-class passengers, 300 second-class, and 1,000 third-class, while the ship's complement is 394. There are seven decks—the boat deck, which reaches from the captain's bridge to the engine-room skylight; the orlop deck, extending forward only, and five other decks which go the full length of the ship. The propellers are three-bladed, the screws being 22 ft. diameter, and having gun-metal bosses. In the older vessels of the White Star line the blades of the screws overlapped; in this case there is a distance of about 9 ins. between the tips of the blades. There are two 18-in. bilge keels 250 ft. in length. The plating ranges from $\frac{3}{4}$ in. to $1\frac{1}{8}$ in. in thickness, and runs up to 29 ft. and 30 ft. in length by 4 ft. 6 in. to 5 ft. wide. The frames are channel section amidships for about two-thirds of the length of the vessel, and are of rolled steel, 9 ins. deep, $4\frac{1}{2}$ ins. on the flange next the skin, and 4 ins. inwards. The centres are $31\frac{1}{2}$ ins. apart. The engines are of the triple-expansion four-cylinder type, with cylinders $47\frac{1}{2}$ ins., 79 ins., and two 93 ins., with 72 ins. stroke. The high-pressure and intermediate-pressure cylinders have piston valves, and the low-pressure valves are double-ported. There are two cylindrical condensers to each engine. The crank shaft is built up and is 25 ins. diameter; the crank-pins 26 ins. diameter. Two thrust-blocks are provided for each engine, and one can take the work while the other is under repair. The air-pump is worked by side levers. The reversing motion is worked by steam and hydraulic gear. The line shafting is $23\frac{3}{4}$ ins. diameter, the propeller-shaft $25\frac{1}{4}$ ins., all of hollow steel. The boilers are in groups of three and four athwart the ship, the largest being 16 ft. 6 ins. diameter, with shell steel plates $1\frac{1}{2}$ ins. thick. In laying her down Mr. Ismay deliberately adopted the policy of a moderate speed, and she carries sufficient coal to make 23,400 nautical miles at 12 knots. She made rather more than 20 knots per hour on her first voyage.

The *Deutschland*, the latest Hamburg-American liner, is a case of a large vessel laid down on another policy, namely, high speed for passenger service. Her length is 668 ft. 6 ins. over all; length between perpendiculars, 662 ft. 9 ins.; beam moulded, 67 ft.; depth, 44 ft.; dead-weight capacity, 6,000 tons; gross tonnage, 16,000 tons; and displacement at 28 ft. draft, 23,000 tons, The hull, which is built throughout of Siemens-Martin steel, contains eight decks, of which the steerage, main and upper decks run continuously

from end to end. The cellular double bottom is divided into 24 tanks, and under the boilers there are four ballast tanks, holding about 66,000 gals. of fresh water for extra boiler feed. Connecting the tanks, is a system of 8-in. piping, and a duplex ballast pump situated in the forward fire-room, having an outward discharge. This pump is capable of discharging 280 tons of water per hour, and in case of failure an auxiliary ballast pump, connected up with 4-in. piping, is ready for duty.

The *Deutschland* has six cylinder quadruple expansion engines, one of which is shown in the illustration, which, however, does not show the two high-pressure cylinders in each set of engines. They are situated above the low-pressure cylinders, and work tandem, their position being indicated by the beds cast on the cylinder tops. The engines are designed to reduce vibration according to Schlick's patent system of balancing, and the cylinders are as follow:—Two high-pressure cylinders, each of 36·64 ins. diameter; one first intermediate cylinder, 73·67 ins. diameter; one second intermediate cylinder, 104·61 ins. diameter; and two low-pressure cylinders of 106·38 ins. diameter, all jacketed, and possessing a common stroke of 72·89 ins.

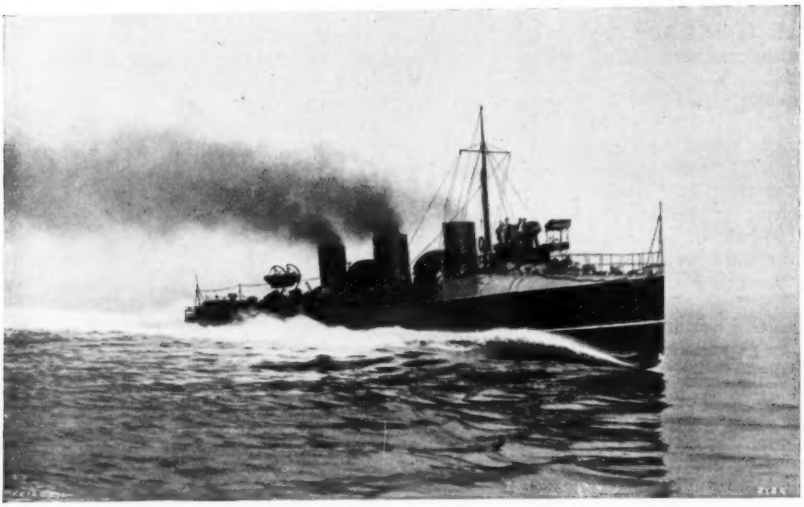
The engines indicate 33,000 h.p. when running at 76 revolutions per minute.

Steam is furnished by 16 boilers, 12 double-ended and 4 single-ended, placed in groups of 4 boilers each—viz., three double and one single-ended in a group. The double-ended boilers are 16 ft. 8 in. diameter, and 20 ft. 3 in. long. Each boiler has eight Morison furnaces, 3 ft. 6 in. diameter, with a grate surface of 2,188 sq. ft., and Howden draft is fitted, giving a total heating surface of 84,250 sq. ft. The working pressure is 225 lbs.

The accommodation is mainly restricted to first and second cabin passengers, provision having been made for 467 first cabin, 300 second cabin, and 300 third-class passengers. The dining saloon, an illustration of which is given on p. 125, is a handsome apartment, reaching across the full width of the vessel, and lighted by a large light, terminating in a dome covered with cathedral glass.

On her return trip to Plymouth, after having made her maiden and outward voyage to New York, the *Deutschland* broke all previous records across the Atlantic, the total distance of 3,073 miles being traversed in 5 days, 11 hrs., 45 mins., at an average speed of 23·32 knots per hour, her engine indicating 35,640 average horse-power.

These two examples show what has been attained in ships of commerce. We have now two examples of what has been reached in the larger war vessel, and that which has been developed for speed alone. Of existing cruisers the *Powerful* and *Terrible* have the highest engine power, but they will soon be eclipsed by the *Drake* class, which are to be fitted with engines indicating 30,000 h.p., and to make a speed of 23 knots per hour. The experiments and trials made by Sir John Durston with the machinery of the *Argonaut*, one of the *Diadem* class of first-class cruisers point out that that ship should be taken as a typical one. The *Argonaut* is of 11,000 tons displacement, 435 ft. long, 69 ft. beam, 25 ft. 3 ins. draught. She is twin screw, and her engines are designed to indicate 18,000 h.p. She is armed with 16 6-in. guns, 14 12-pounders, 11 smaller quick-firers, and machine guns. She makes 20·75 knots an hour at full power, and can carry 1,000 tons of coal. The engines consist of two sets of the triple-expansion type with four cylinders; the boiler pressure is 300 lbs., and steam at engine 250 lbs. The cylinders are 34 ins., 55 ins., and two low-pressures of 64 ins., stroke 4 ft. Her designed speed is 120 revolutions. The cylinders are all steam jacketed and are arranged high and intermediate forward, and the two low-pressures aft. The cranks of the first pair are opposite each other, so are the next pair, but the first pair are at right angles to the second pair. The two first have piston valves, the second pair double-ported slide valves. The reversing gear is of the all-round type. Thirty Belleville boilers supply steam, and these are fitted with economisers. They are arranged back to back in four



H.M.S. "VIPER."
WITH PARSON'S TURBINES, DEVELOPING 10,000 I.H.P. AND MAKING 36 KNOTS PER HOUR.

groups; transverse bulkheads divide the boiler space into four compartments. The heating surface is 47,300 sq. ft. Each engine has a condenser with 19,000 sq. ft. of cooling surface, and each is provided with two circulating pumps, 45 ins. diameter, and each capable of discharging 1,200 tons of water per hour from the bilge. The evaporating plant can produce 90 tons of water per day when worked non-compound, and 56 tons when compound, and there is an auxiliary condenser for the auxiliary engines. There are a steering, a ventilating, electric-light, and two fire and bilge engines in each engine-room; also a third electric-light engine in another compartment. To each stokehold there is a furnace air-pumping and ventilating fan, and each boiler-room a main and auxiliary feed engine. There are engines about the ship for air-compressing, boat, coal, and ash hoisting, capstan working, and refrigerating.

A trial was made with her engines developing 3,784 i.h.p. for a period of 30 hours. She made 73·1 revolutions of screw; her piston speed was 584·8 ft. per minute; pressure at engines 160·5 lbs.; the consumption of coal was 2·03 lbs. per i.h.p. per hour. When developing 12,785 i.h.p. she consumed 1·66 lbs. per i.h.p. per hour, made 106·5 revolutions per minute, and, at full power for eight hours, made 123·6 revolutions, and consumed 1·64 lbs. of coal per i.h.p. per hour when developing 19,325 i.h.p.

Sometimes steam was used in the jacket and sometimes not. There was an increase of water consumption when steam was used in the jackets of 5·8 per cent. at 18,000 i.h.p., 2·6 per cent. at 13,500 i.h.p., and $\frac{1}{2}$ per cent. at 3,600 i.h.p.

With expansions ranging from 10·4 to 8·3, the water used per i.h.p. ranged from 15·44 to 16·22 lbs. per i.h.p. per hour, and when the expansions ranged from 15·7 to 8·3 the water used ranged from 16·26 to 17·72 lbs. per i.h.p. per hour.

When developing 3,600 i.h.p. the auxiliaries took 22 per cent. of steam; when developing 13,500 i.h.p. they took 10·4 per cent. of the steam.

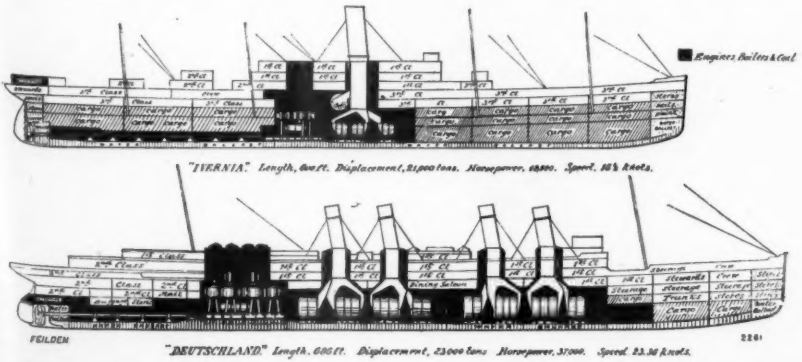
The Admiralty has adopted the Belleville boiler, of the water-tube economiser type, for their large cruisers. Indeed the policy of the Admiralty is to fit all vessels

built for them with water-tube boilers, because of the tactical advantages offered by that type. For, while it is dangerous to get up steam in the cylindrical boiler sooner than in eight hours, it can easily be got up in the water-tube type in twenty minutes without any risk to the fittings. This tactical advantage of the water-tube boiler was demonstrated very clearly when Admiral Cervera's fleet rushed out of Santiago Bay and tried to escape. Admiral Sampson, who was watching the Spanish Admiral, had immediately to get up steam and give chase. Had he been required to remain for eight hours getting up steam before he could have given chase, his task would have been hopeless. Then the question of weight comes in as well as tactics. It would be impossible for the Parsons turbines fitted in the *Viper* to obtain sufficient steam to indicate 10,000 i.h.p. from cylindrical boilers, and carry them in so small a vessel. The limits of weight-carrying capacity and space set aside for boilers in high-speed torpedo craft make it a necessity of using water-tube boilers.

The Admiralty separates water-tube boilers into two types—the large-tube type, like the Belleville, and the small tube type, like the Thornycroft and Yarrow. Their policy with regard to these two types is to fit in vessels larger than the third-class cruiser water-tube boilers of the large tube type, and in vessels from the third-class cruiser downwards boilers of the small-tube type. The cylindrical boiler has been discarded.

Boilers of the water-tube type are not quite so economical as the cylindrical. On rare occasions, and with trials made under exceptional conditions, the consumption of coal with water-tube boilers has been found to be as low as 1 lb. per i.h.p. per hour. But this is not what is found to be the usual consumption when the vessel is cruising under ordinary conditions. The evaporation of a water-tube boiler when forced in a destroyer is a little over 6 lbs. per lb. of coal.

That so great a perfection in the construction of steam turbines for marine purposes has not been attained may be granted without any fears that such will be gained. The coal consumption of the *Viper* is not yet on quite as good a footing as the economy of the reciprocating engine. The *Viper* is a sister torpedo-destroyer to the *Albatross*. She carries the same weights and has the same lines. On one of her trials she made 36 knots, on another 33·838, and burned 25,685 lbs. of coal per hour. The destroyers, fitted with reciprocating engines, cannot make more than about 31 knots, but at the present time burn a little less coal. In these boats everything is sacrificed to speed, and it is hardly a fault


Engines Boilers & Coal
"IVERNIA." Length, 600 ft. Displacement, 21,000 tons. Horsepower, 18,000. Speed, 16½ knots.
FEILDEN
2281
"DEUTSCHLAND." Length, 686 ft. Displacement, 23,000 tons. Horsepower, 37,000. Speed, 23.36 knots.

THE S.S. "IVERNIA" AND S.S. "DEUTSCHLAND" COMPARED, SHOWING RELATIVE SPACES OCCUPIED BY ENGINES, CARGO, AND PASSENGERS.

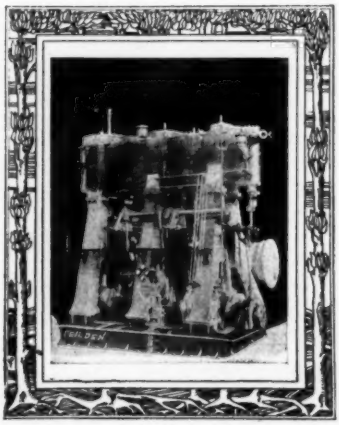
(From the *Scientific American*.)

that the *Viper* should consume more coal than others, so long as she makes more speed. But the presumption is very strong that the economy of these turbines will be greatly increased in the future, since the economy of electric lighting steam turbines is very high. One of these turbines was on trial a short time ago, and made the following performances. It was a 1,000 kilo-watt set :—

Load.	Load in Kilo-watts.	Use of Steam per hour.	Use of Steam per hour per Kilo-watt.
One	1,250 ...	23,600 ...	18·9
Full	1,000 ...	19,940 ...	19·9
Three-quarter	750 ...	16,150 ...	21·5
Half	500 ...	12,140 ...	24·3
Quarter ...	250 ...	8,020 ...	32·1

At 1,250 kilo-watts the consumption of steam is nearly 12 lbs. per i.h.p. The speed of the engines of the *Cobra* and *Viper* is 1,000 revolutions per minute. The inventor is quite sure he will be able to increase the economy of the engines when the destroyer is making a cruising speed.

Chas. Halliday



Modern Workshop Practice.

By EWART C. AMOS, M.I.Mech.E

THE last few years, and especially the last three, have seen a great revolution in workshop practice, brought about by causes to which reference will be made in this article; and, further, it may be said that this process of re-organisation is in full swing at the present time.

In order to focus the subject to some extent, it will be necessary to treat it under two headings, viz., "General Causes" and "Resultant Practice," these, again, being further subdivided.

GENERAL CAUSES:—FOREIGN COMPETITION.

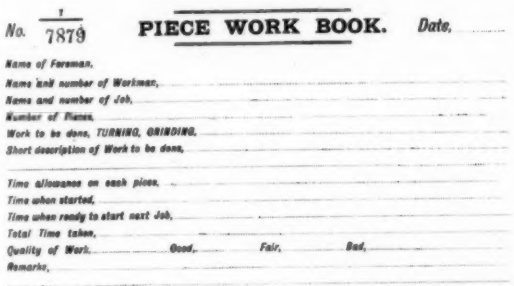
Modern Workshop practice is largely the product of foreign competition. The time was, and that not so very long ago, when this country was the engineering workshop of the world, and the necessity for keeping down prices did not trouble us as it does now. We had our labour troubles, it is true, but whilst we could obtain high prices for our goods (which were of a kind difficult to obtain elsewhere) these troubles did not affect us, and we continued to make use of a plentiful supply of manual labour much in the same way as we still waste our coal and fuel products at the present time.

In America, however, labour secured a higher wage, not relatively, but simply because of the different value of money; and, as a result, American engineers and designers sought to reduce cost of production by reducing the labour factor as far as possible. This enabled them to import manufactured goods into this country, and to compete with us, notwithstanding the high wage and cost of transit. Having made the producing machines for themselves, it was a very easy and natural step for them to commence the exportation of machine tools.

THE IMPORTATION OF AMERICAN AND OTHER TOOLS.

It has been said that we only get a surplus stock of what America is unable to use herself, that this is produced at a loss, and that in proof of this, an American tool can be purchased cheaper in England than in America, although burdened with cost of transit, etc. The writer feels some difficulty in accepting this statement, but what is true is that America, and to some extent Germany, are placing tools here which compete in price, quality, and design (and in many cases more than compete in their capacity for output) with our best machines, and yet they have to pay freight, and higher prices both for labour and material. How do they do it? The reasons are several, but may be condensed into two, viz., By devising machines to save time, and by reducing the amount of manual labour to the lowest possible factor. Their organisation of workshop methods, their system of standardisation, their treatment in fact of the raw material, differs from ours from beginning to end. There are yet two points to be considered: first, American tools are being somewhat "boomed" just now, and further, are often more easy to obtain from stock than British tools; secondly, the questions of design and capacity enter largely into the causes of their popularity. As a matter of fact, the capacity of a tool indicates its true value. Instances have occurred, over and over again, of British makers losing orders, not because their machines were not as good so far as workmanship was concerned, but because the American tool could give an increased output owing to superiority of design and ease in working. Whilst fully bearing in mind the enterprise and inventive qualities displayed by our own engineers, it will largely be admitted by all who are unprejudiced, that one of the prime factors that has produced modern workshop practice has been the introduction of the American tool into this country. In referring thus to the American tool, and its effect upon ourselves, it must also be

admitted that there are evident signs that our own manufacturers do not intend to be left behind, and the last few years have seen immense improvements in the home-built tool—so much so, that it looks as though the American makers will soon find severe competition in the special machines by which they have largely controlled our market. Nor has the inroad of these foreign machines been so detrimental as might at first sight appear, but rather has it been of much assistance in enabling our manufacturers to deal with the large amount of business which they have received and are receiving at the present time. Not only in the cycling trade and amongst general engineers has the American tool been of value, but our tool-makers are using it for the manufacture of those very machines with which they are now competing against the foreign article. It may be said that this is paying a great compliment to the American machine-builder. Whether this is so or not, it is at any rate a fact, and indicates an excellent business capacity on the part of our makers, who recognise merit when they see it and yet endeavour to beat it, and so we may expect much progress in the near future.



No. 7879 **PIECE WORK BOOK.** Date,

Name of Foreman,
Name and number of Workman,
Name and number of Job,
Number of Pieces,
Work to be done, TURNING, GRINDING,
Short description of Work to be done,

Time allowance on each piece,
Time when started,
Time when ready to start next Job,
Total Time taken,
Quality of Work, Good, Fair, Bad,
Remarks,

Signature of Foreman that the Work has been Examined and found Correct,

FIG. 1.—SAMPLE SHEET TAKEN FROM A BONUS PIECE-WORK BOOK.

THE LABOUR QUESTION.

It will be generally admitted that the labour question enters into and largely dominates workshop practices and methods, and therefore proper recognition of it is essential, since, after all, it is the main factor. However automatic we may make our machines, and whatever saving may be effected by such automaticity, we are still dependent upon the human factor to work or superintend the working of these machines. The subject has already been dealt with very extensively, both in the press and on the platform, but its difficulties have by no means yet been solved, and the world is still in the throes of a labour war; not so apparent at the present moment, but still smouldering under the surface, and likely to break out at any moment.

It is naturally the subject of much controversy, since most writers and those who are actively engaged in its solution regard it from one of two points of view, viz., either that of the employer or employee, and while space prevents its full consideration here, a brief reference to its salient features may be of interest. This is a world of progress towards perfection, however much such advance be apparently retarded at times; and to speak of the solution of any great social question such as this is merely to refer to a solution in terms of degree.

A refusal on the part of capital to consider the just demands of labour is as disastrous to both as the attempt on the part of labour to restrict output, in order to avoid a surplus labour market, or similar reason. Demand is generally supposed to regulate the supply, but if we take the case of importation of American tools into this country, we find that the supply actually produced the demand. So long as the employee (typified either by the individual, or by a union) demands a restricted output on the one hand, and the employer attempts to secure a surplus of labour on the other, a just and equitable settlement of the difficulty must remain in abeyance. The result so far

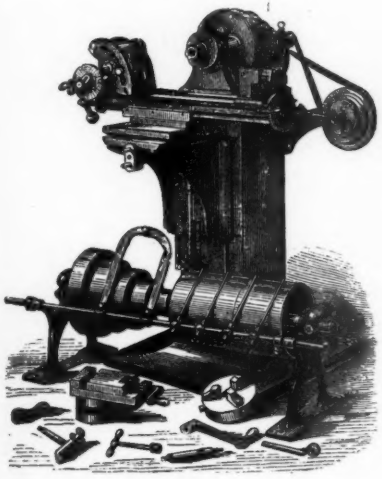


FIG. 2.—ORIGINAL DESIGN OF A BROWN AND SHARPE NO. 1 UNIVERSAL MILLING MACHINE AS BUILT IN 1876.

has been to produce strikes alike disastrous to capital and labour, and the country at large outside the particular industry affected. For a period capital appears to gain an advantage, followed by a similar gain to labour. The idea that labour-saving tools are injurious to labour is a fallacy long since proved. They are the emancipator, not the destructor, of the manual worker. At the present time the labour-saving automatic machine is immensely on the increase, but there is no corresponding diminution in the demand for labour. So long as there are people wanting the bare necessaries or even moderate luxuries of life, there cannot be said to be an over-supply; it is true there may be the absence of means to procure such necessaries or comforts, but when the producer and the thing produced stand in their proper relations to each other in respect to the amount given to the former in return for his work (whether mental or physical) in bringing about the latter, the difficulties of over-production and surplus labour markets will have solved themselves. Leaving for a moment general considerations, let us turn to the various methods of payment adopted. Roughly, they may be divided into three:

(1) Time-work, or payment per hour.

(2) Piece-work, or so much per piece or part, irrespective of time.

(3) Premium-work, in which the workman is assured of his regular wage with the opportunity of earning a bonus on all work which he completes under a time limit agreed upon. This latter system is subject to various modifications, and none of the systems given above takes into consideration the payment of foremen, managers, draughtsmen, &c., who receive a fixed payment by the week, month, or other period with, in some cases, a bonus based on profits.

Time-work (1) is the system most in vogue, and so far as certain classes of work are concerned must always remain so; for instance, in repair shops, or where repetition work does not occur, and it is difficult to obtain any standard time or quantity. It does not follow, however, that some participation of profits should not be offered to the ordinary time-worker, and this system is in fact carried out in certain works at the present time. The plan is, however, not without its difficulties, amongst others being the proper consideration of the interest, however small or indirect, which each employee has in the business in the event of his discharge. This claim is, however, generally disregarded.

Piece-work (2). This system has been, and still is, the cause of an unusual amount of friction both in this and other countries, especially America. So much is this so that employers, even where not compelled by the unions, have in many cases abolished it, and have substituted the third system mentioned, viz., that of premium-work. Before, however, discussing this, it may be interesting to note the points for and against piece-work. It still exists to a considerable extent, and in some cases may prove satisfactory, especially if, as is generally the practice in America, the fixed price is based on time and a quarter, with the further possible reward to the workman, that if he can increase the output by devising some new methods he is allowed to continue on the

old basis for such a time as will enable him to secure a fair reward for the industry and ability he has displayed ; after this, the price comes down again to time and a quarter, and he proceeds as before. It must be understood that the increased output is the result of devising new methods or improving the tools employed, rather than increased physical effort ; and whilst the man works no harder, he secures for his employer an increased output, which is rewarded in the way described. It may be said that the advantage thus gained is to him only temporary, but to his employer permanent ; but, on the other hand, he would be no better off if he still continued on the old system, rather would he be worse off, since he would be without a bonus. Again, the increased output may necessitate the substitution of new machines or appliances, and whilst the employer may be glad to put these down, yet the capital expenditure has to be taken into consideration. This system of piece-work really approaches the premium system, which will be discussed later, and it is difficult to separate the two. As a large employer of labour recently said to the writer, even on ordinary piece-work, if the men fail to make up to their regular wage they generally expect it to be made up for them, so that it comes much to the same thing ; but as regards ordinary piece-work everything points to its general discontinuance in the near future, unless accompanied by some form of bonus or guarantee. Piece-work, moreover, frequently induces rivalry and discord amongst the men, besides lowering the standard of efficiency, alike producing injury to the employer and employee. It increases output in certain cases, but where it is carried out to any extent organised labour steps in sooner or later and retaliates by the adoption of some measure which limits its effects. The premium system is an attempt to reward the best workers in proportion to their efforts, without at the same time injuring the position of the less skilful ones. From the point of view, however, of those who desire to limit production it works more in favour of the employer than of the employee, and as an example of its effect the following case may be stated.

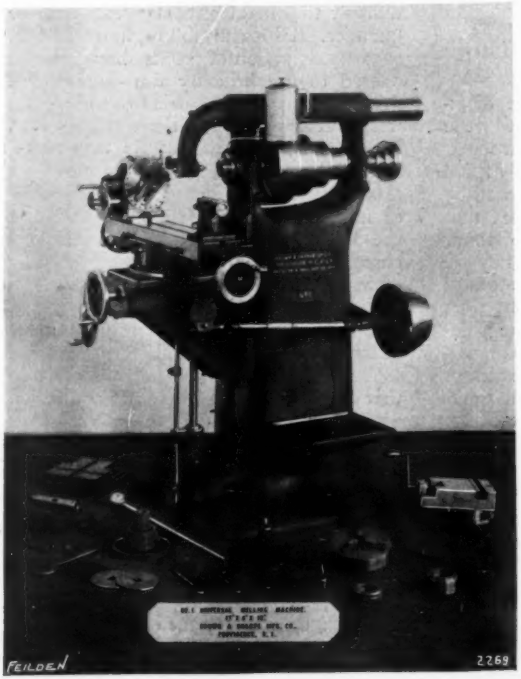


FIG. 3.—LATEST TYPE OF BROWN AND SHARPE NO. 1 UNIVERSAL MILLING MACHINE AND ATTACHMENTS.

Supposing the amount paid per week in wages is £500, and by the introduction of the premium system this amount is increased to £600. The men gain an advance in wages equal to 20 per cent., but the output of the shop has increased by 40 per cent., assuming that the premium paid is an equal division of wages on the time saved. So long, of course, as the employer can find a market for his

increased output, and does not reduce the number of his employees, they cannot be said to be the losers, since they are co-partners with their employer in this increased prosperity; but the fear on the part of the men's unions appears to be that increased production means restricted labour, an attempt, in fact, on the part of the employer to produce a surplus labour market, by means of which he can dictate what wages shall be paid. As already stated, here lies the root of the question. In connection with piece- and premium-work, it may be interesting to refer to opinions held by different eminent firms. A well-known tool-maker recently told the writer that he uses a collective piece-work system throughout his works, *i.e.* he has prices for the whole of the turning, planing, boring, drilling, milling, gear-cutting and fitting for every machine made. On the other hand, the writer understands that about three years ago some firms in the North of England came to the conclusion that piece-work in that part of the world was on a very unsatisfactory footing, and decided to abolish it. At the beginning of this year, however, one large firm with whom the writer is acquainted adopted a system of premium payment with their machine work. This has proved, as far as it has gone, to be a very satisfactory step. The premium paid to the men is based entirely upon the amount of time saved as against the estimated time allowed for the work, and, once fixed, the time allowed for the work is not altered unless alterations are made to the machine on which the work is done, which would considerably modify the time of the operation. However, like all systems of piece-work, it entails a very considerable amount of care and experience in making the estimate for the time to be allowed on an operation which has been previously done on a time basis. The premium system is one which is very difficult to adapt to hand labour, such as fitting and erecting, and they are gradually introducing this as they feel their way. A well-known London firm, who approve on principle of piece-work, are obliged to admit its serious drawbacks in actual practice under certain conditions. In a general way, they consider piece-work to be the fairest and most satisfactory way of remunerating workmen, but there are many things to be considered. In the first place, with new designs it is impossible to fix a fair piece-work price. The first lots have to be produced in small quantities, and without the best appliances, and must entail more skill and labour than when the design has proved a success and can be put through in large lots. Such a difficulty could be met by changing the price whenever the conditions changed, but unfortunately there is rooted objection

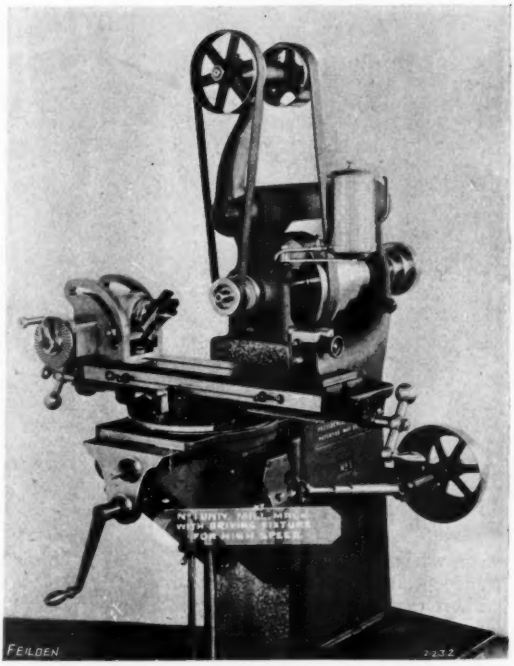


FIG. 4.—NO. 1 BROWN AND SHARPE UNIVERSAL MILLING MACHINE, FITTED WITH DRIVING FIXTURE FOR HIGH SPEEDS

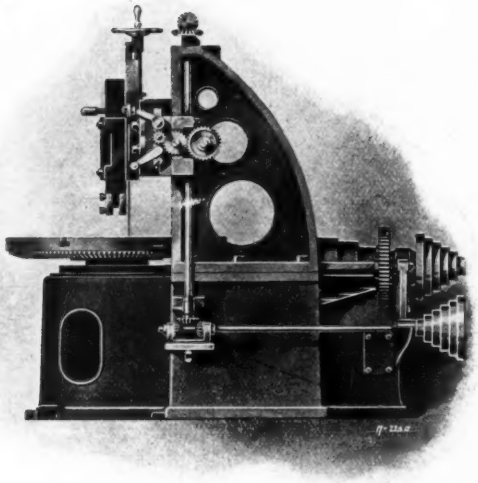


FIG. 5.—ORIGINAL DESIGN OF "BULLARD" 37-IN. BORING AND TURNING MILL, AS BUILT IN 1883.

among workmen against change of piece-work prices, and it is manifest that it must appear to them that the quicker they work the lower the price, and encourages them to hang out on the work to avoid reductions. This is done very cleverly at times, and is very general everywhere. Another great evil in piece-work is, that the most skilful men are required to do the new and odd jobs referred to above; and as these are done day-work the result is that the skilful man gets day rate, whilst another man who can only do repetition work earns much higher money piece-work. To deal with these difficulties they have tried various bonus systems, but they appear to think that these lack the stimulus of the piece system. Moreover, they consider the matter is so surrounded with difficulties that it would be unwise to commit themselves to any definite opinion. In Germany, as here, various systems are in vogue. An eminent manufacturer there informed the writer that he pays per hour, and has also a system of paying a premium, which he considers the fairest way of remuneration. The workmen are induced by such a system to increase their work as much as possible, and this plan is therefore adopted extensively. The writer is able to reproduce—as seen by Fig. 1—a sample sheet, taken from a bonus book of an eminent firm of machine tool builders in Scotland who have kindly afforded this information, and this will help to illustrate one form of the premium system, and is fairly typical. A workman is allowed, say, ten hours to machine twelve pieces,

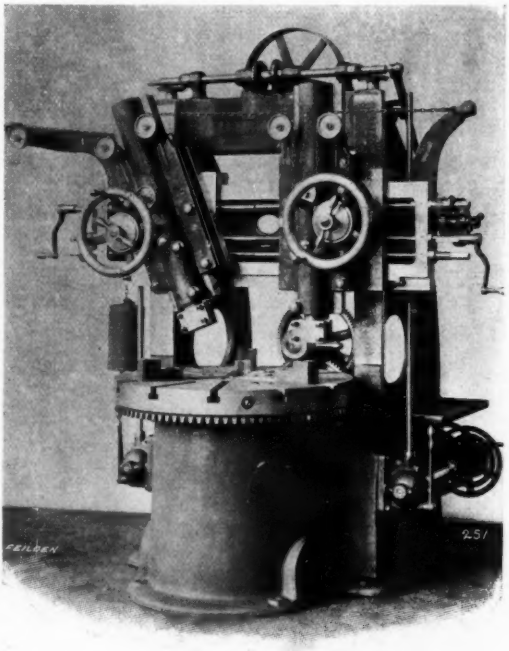


FIG. 6.—PRESENT DESIGN OF 37-IN. "BULLARD" BORING AND TURNING MILL.

but should he finish them in six hours, he is paid two extra hours bonus for this saving of time, sharing equally with his employer on the time saved; but although he only gets half, on the other hand he loses nothing should any piece be spoiled during machining, even if it has already passed through a number of operations. As is known, blow-holes frequently appear on castings after a considerable amount of work has been done on them, and all responsibility of such loss is taken by the employer. In addition to this, the firm referred to are willing to supply the workmen with any tools for finishing the work quicker or better.

Yet another illustration may be given. In this shop, for a long time, piece-work and day-work have been combined, and worked fairly well but for the fact that there is always a chance of error and actual misappropriation unless the day-work is very strictly checked. Recently, however, a bonus system has been adopted, whereby the men share equally in the benefits arising out of the saving effected by greater push and better methods. This is done in two ways. (1) By computing, by experience or otherwise, the time necessary to do a job, adding 30 per cent. to this, and sharing any saving with the men. If no saving is made below that at which the original time was set, the men would get 15 per cent. The system works well because it removes all temptations to keep reducing prices when the men are earning good money, and which often has been the cause of suspicion in the minds of the men, and of regulating the speed so as to just earn so much bonus as will not attract attention and cause the prices to be lowered. It has the advantage, that if mistakes are made in the first instance in the rate set the error is reduced by one half. It is also not necessary to have a whole series of prices for men at different rates of pay. (2) In bridge work a variation of this system is adopted, where a time rate is difficult to establish, by giving the gang a lump sum for wages—say, for instance, £250. At the end of the job, any saving below this is divided between master and men. Of course, there is no

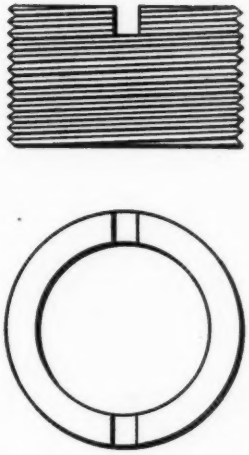


FIG. 7.—BRASS CONDENSER FERRULE.

getting into debt by this system, which is a great advantage; and it is quite as effectual as the piece-work in weeding out those who won't do a good day's work. The same works have also adopted the one-break day—namely, the men start after they have had their breakfast at home, and stop only again for their dinner. Under these arrangements they work 52¼ hours per week, and each man who makes full time during the week receives 1¼ hours bonus for doing so. This arrangement was only started on October 1st, but there is an immense improvement already on the time made all through this shop. The one-break day is in many ways advantageous, as there is a saving of the loss of time stopping at the breakfast hour, and the saving incidental in not having to warm up engines and steam pipes for that purpose; the men also have only got twice a day to waste time taking off and putting on their coats instead of three.

Further examples might be given, but these will suffice to illustrate a system which is being extensively adopted.

CONTRACTS.

This system pertains partly to the piece system, although, when carried out on the American plan, it assumes proportions that are very extensive and somewhat

different. In the first place, a foreman or other responsible employee, contracts to complete a job, or part of a job, at a price agreed upon with his principal. He engages and pays the men employed upon the job. Under certain conditions this system may answer; on the one hand, it enables the master to know beforehand the cost of a job, on the other hand, however, it sets up, to some extent, a dual authority and creates friction in many ways that can easily be imagined. Contracting, as understood in the States, is where a man, generally an expert in the best methods to employ for reducing the cost of production, who takes over from the owners the running of the whole concern, frequently brings his own men, and, in the event of disagreement between the contractor or owner at the termination of the contract, takes these men with him to the next shop he takes over. The contractor undertakes to give a certain output, the owner finding the market and advancing payment as the goods are produced, this being a question of terms, although the contractor has to generally finance to some extent. Many of the best known American shops are run on this system, and at least one in this country is being worked on the lines above described.

In concluding these remarks on the effect of the labour element in modern manufacturing, the writer wishes to emphasise two aspects of the case, although they are, at the present time, the subject of much controversy. (1) That so long as combinations, either on the part of master or men, continue to be necessary, they should be used for the purpose of settlement of disputes, rather than for forcing either side into unfair positions. That whilst the men's unions are justified in protecting their members from over and incapacitating exertion, they should not attempt to secure a limited output, since this is almost, without exception, contrary to all economic conditions, and is never likely to achieve its end. Again, that whilst such unions are formed for the purpose of obtaining as high a wage for their members as possible, due regard should be had to the conditions existing, and the more general acceptance of a sliding scale that works both ways, instead of with only an upward tendency, might encourage the employer to terms of greater generosity in times of prosperity. (2) That the employer, on the other hand, should pay the highest wages possible, consistent with the market conditions, without waiting to be forced, either by the unions or by

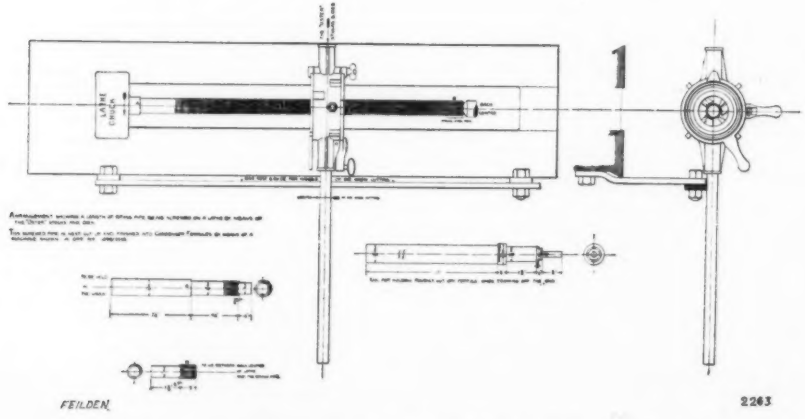


FIG. 8.—METHOD OF SCREWING TUBE FOR MAKING BRASS CONDENSER FERRULES

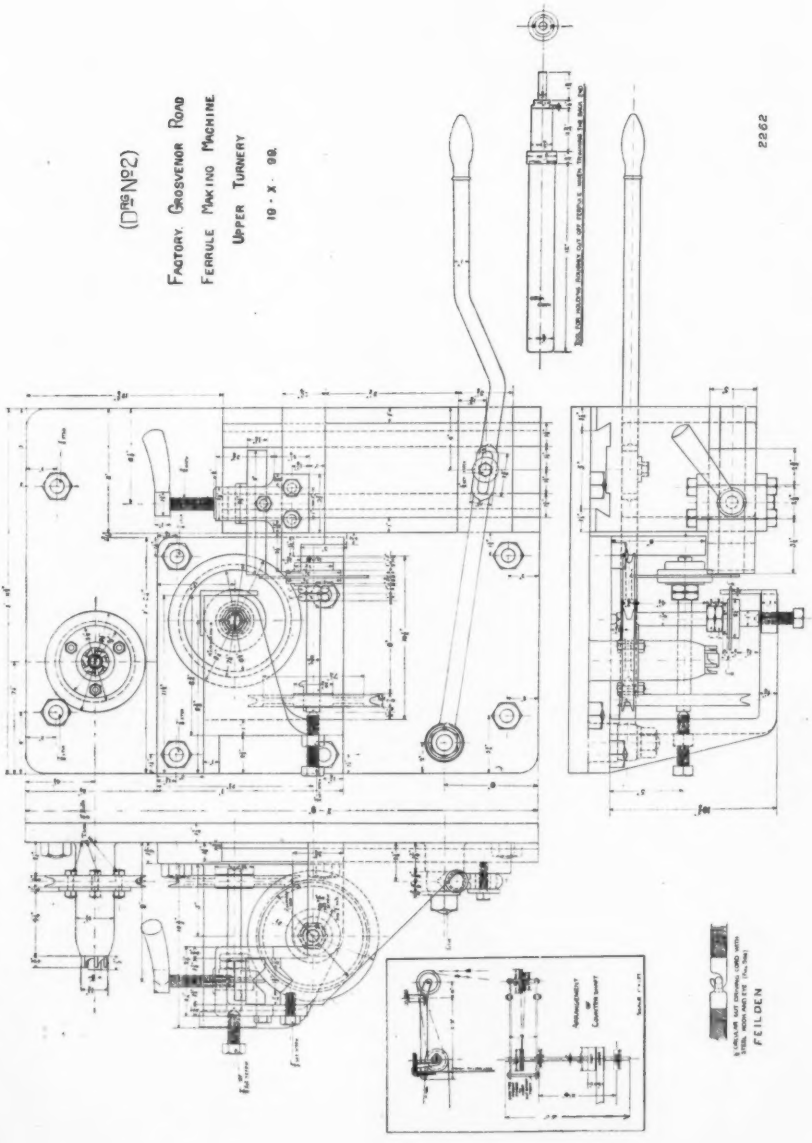


FIG. 9.—BRASS CONDENSER FERRULE CUTTING-OFF MACHINE.

scarcity of labour. That the environment in which the employee is expected to work, should be in harmony, as far as possible, with those hygienic conditions that the employer himself usually enjoys, viz. :— fresh air, light, warmth and cleanliness. Since, even supposing he provides these conditions for no higher motive, it is a well-known fact that the capacity for output of the human machine varies directly with the presence or absence of these conditions ; and still more is this true if the men are in possession of a wage which not only relieves them of anxiety as bread-winners, but is also a fair return for their exertions.

Enthusiasm in their work, and happy relations between employee and employer also not diminished, but rather increased, by the introduction of bonuses or participation in profits, which profits are generally brought about by the efforts of the human factor, notwithstanding the employment of automatic machinery.

The writer is an advocate of the payment of good wages, but this is only possible where the manufacturer can also get good prices for his articles. We are told that foreign competition largely makes this impossible, and this is perfectly true in a great many cases ; but those manufacturers who turn out a first-class article, the production of which is only possible by the use of accurate and up-to-date tools, plus well-paid employees, can always secure good prices, and generally have less to fear from foreign competition than those working under obsolete conditions. It may be advanced that the payment of higher wages will produce higher prices in the finished article, and that, therefore, the workman when in the position of a purchaser will thus find that his higher wage has a less purchasing power. This may be partially correct, but it generally exists only for a time, since improvements in machinery producing things in greater quantity and more cheaply has been concomitant with a rising wage, and instead of bringing about over-production has increased the demand.

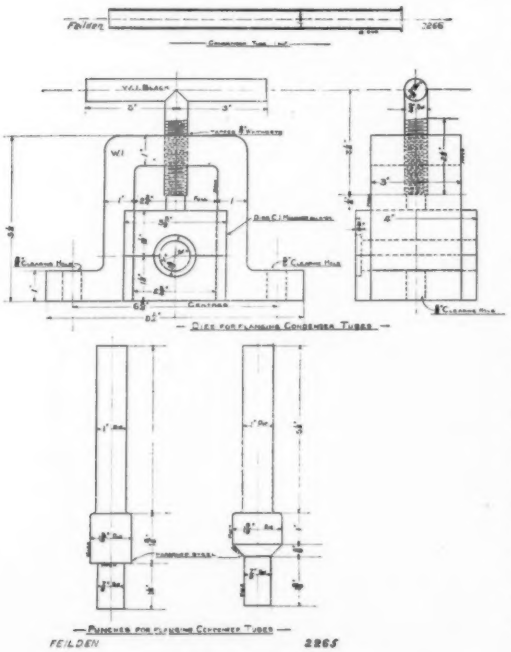


FIG 10.—ILLUSTRATING PUNCHES AND DIES FOR PRODUCING THE FLANGED ENDS OF BRASS CONDENSER TUBES.

SPECIALISATION.

The questions of specialisation and standardisation have been dealt with by the writer on more than one occasion, but their importance, far more widely appreciated to-day than they were, say, five years ago, cannot be too frequently urged upon our manufacturers. A leading British maker of machine tools, whose manufactures up to a recent date were of a considerably varied description, informed the writer lately that they are now consolidating and standardising, confining themselves ,in fact, to a limited number of types of machines, with several sizes of each kind ; and this may be taken as an example of a rapidly growing practice—a practice almost universal in America.

Whilst this restriction in types is advantageous and possible in certain classes of machinery it is, of course, quite impossible in a great many, and cannot be resorted to to effect saving, although there are few classes of engineering where the principle of specialising cannot be adopted in some shape or another. Again, in large work—where the spring of the metal requires considerable skill and judgment in setting and machining, in order to avoid distortion—the specialised labourer has to give way to the skilled mechanic, and the management of large and expensive machine tools must necessarily remain in charge of the experienced operator, who must, in fact, not only be possessed of intelligence, but must exercise it at every turn in order to overcome the constantly recurring difficulties which present themselves in all large work. On the other hand, the specialised labourer whose duty it is to repeat the same article again and again, whose machine even is frequently set by the foreman, is apt to develop into a mere machine himself, and it is this human feature of specialisation that is becoming a serious industrial problem. The results obtained by standardisation in respect to the smaller classes of work are so encouraging that it is, no doubt, only a question of time when by the use of special jigs, fixtures, and machines, its principles will be applied to still heavier machines.

TYPES OF OLD AND MODERN TOOLS.

Machine tools and workshop practice bear such a close relation to each other, that it becomes necessary to make some reference to the machines in order to bring home more vividly the different systems. It has been thought well, therefore, to illustrate a few types of both antiquated and up-to-date machines. By antiquated it is not meant machines of one hundred years ago, or even half that age, because the last few years has seen such rapid changes that in most cases ten years is more than sufficient to justify the term "an old-fashioned machine."

Fig. 2 shows an early pattern of a Brown and Sharpe No. 1 Universal

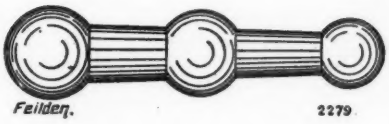


FIG. 11.—BRIGHT-TURNED AND POLISHED BALANCED HANDLE, TURNED FROM THE SOLID BAR AT A COST OF ONE-TENTH OF A PENNY.

(Drawing about two-thirds full size.)

Milling Machine, introduced into this country by Messrs. Charles Churchill and Co., Ltd., in the year 1876, or, say, a quarter of a century ago, a date which will doubtless be a surprise to many. A machine exactly similar to this, and built in that year, has recently been an exhibit at the late Paris Exhibition, alongside one of the latest types, as shown by Fig. 3. As will be seen by reference to the cuts, the main principles of the earlier type have been embodied in the new, the chief difference being in matters of detail, and with the addition of a greater number of attachments which enable it to assist modern practice. Amongst the chief improvements may be noted the overhanging arm carrying outer support for mandril, circular motion to table, stop motion to slides, overhead motion with friction pulleys and clutch instead of double belts, as shown in the illustration of old machines. The latest type of the No. 1 machine is also made in various designs for special work. Fig. 4 shows the same machine fitted with a driving fixture for high speed in place of the overhanging arm and outer support. It may be interesting to state that the 1876 machine was sold at £140, while the present machine, as shown by Fig. 1, complete with attachments, only costs £118.

Another comparison may be made, as between an old and a modern boring mill. The type selected is that of the well-known "Bullard" mill. These machines were first put on to the market in America about the year 1883. Fig. 5 illustrates their original 37-in. mill, whilst Fig. 6 shows one of the latest types of a similar size, which is fitted with two heads. Among many improvements may be

noted: (1) fitting of the table with self-centring jaws built into it, which jaws can be removed and independent ones substituted as desired; (2) cross rail raised and lowered by power; (3) the whole machine is more compact, occupies less space, and possesses a more rigid and greatly strengthened frame; (4) cased-in feed-gears; (5) cross-slide fitted with two heads instead of one.

This and the former illustration of the mill indicates the great improvements effected in a comparatively short time.

SOME EXAMPLES SHOWING THE SAVING EFFECTED BY MODERN METHODS.

Through the kindness of Mr. C. L. Simpson (Messrs. James Simpson & Co., Ltd., of London) the writer is able to reproduce the drawings of a small machine employed in their works for the production of brass condenser ferrules. Such a ferrule is shown in Fig. 7. These originally cost 1*s.* 9*d.* per hundred to machine, but by the adoption of the machine illustrated the cost of production from raw material has been reduced to 1*s.* per hundred. Under the old system a solid drawn tube about 2 ft. long was placed in an ordinary lathe, and a thread cut by means of the screw-cutting motion; a solid die was then run up and this screwed tube was then parted off in the lathe into the widths of the ferrules, and the two nicks or slots seen in Fig. 7 (which are for the purpose of screwing the ferrule in the tube-plate) were cut out by a saw in a separate machine, and the cost of machining was as stated above. Now, however, the process is as follows (reference being had to Figs. 8 and 9, in which Fig. 8 illustrates the present method of screwing the solid drawn brass tube in an ordinary lathe by means of a set of "Oster" stocks and dies):—The plate is self-explanatory. On removal from the lathe after being screwed, it is introduced to the machine illustrated by Fig. 9. This is for the purpose of dividing up the screwed tube into short lengths, and at the same time finishing-off the faces and making the nicks previously referred to. As will be seen, the machine possesses two circular saws, with their spindles placed at right angles and driven by gut-band in the way shown. The screwed tube is held in a suitable vice, mounted on a slide actuated by the hand lever seen on the right, and by raising this lever it first presents the tube to the upper saw which produces the nicks, and by depressing it the lower saw is caused to sever off a portion of the main screwed tube, thus producing a ferrule. These are then mounted on the special mandril shown, and presented to the revolving cutter (seen in the top portion of the machine) for trimming off the back end. The machine as designed is arranged to be bolted to a wall or similar support, and occupies very little shop room. Fig. 10 illustrates the dies and punches used for producing the flanged end of a brass condenser tube; a finished flanged tube is seen at the top. To produce this result, a solid drawn tube is placed in the dies seen on the left. The right hand punch is then driven in; this partly produces the flange, which is finally produced by the introduction of the square shouldered die seen on the left.

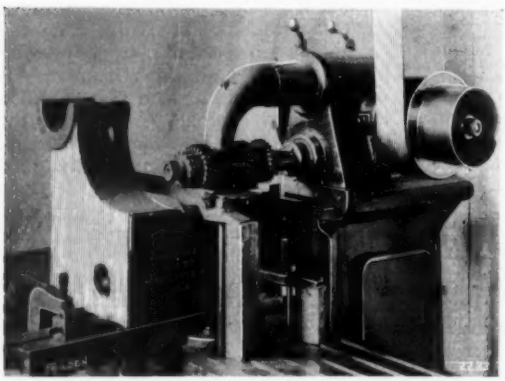


FIG. 12.—UNIVERSAL MILLING MACHINE, OPERATING WITH A GANG OF CUTTERS ON SEVEN SURFACES AT ONCE.

Referring now to some further examples of reduction in cost, due to the substitution

of modern for old-fashioned tools, it may be stated that by the use of a chasing lathe, small gun-metal stuffing-boxes, which previously cost 5*d.* each to machine on an ordinary lathe, are now being machined for 2½*d.* each. Again, small slide-valve spindles, as used for donkey pumps, can now be made for half what they originally cost, by turning them out of the solid in a Jones and Lampson or similar lathe, as compared with forging them first, and turning in an ordinary lathe, which was formerly the usual practice. This is one illustration of the great saving effected, not only by means of an improved tool, but by adopting another method in turning out of the solid as against forging and then turning, a system made possible by the type of tool used. As an illustration of the saving effected by milling over planing and slotting, a steel crosshead, having six faces to be machined, when milled with a roller cutter on a slab miller cost 1*s.* 6*d.*, as against 5*s.* 6*d.* when planed and slotted. In drilling holes in flanges of pipes, cylinders, &c., it is found that by using a multiple drill of the Bausch and Harris type, having the spindle adjustable to various circumferences of holes, and all drilling at once, a saving of 20 per cent. to 30 per cent., according to nature of work, is easily effected, as against single spindle drilling, and adjusting for each hole. It must not be forgotten, however, in considering the saving effected in the various examples given, that due allowance must be made for the extra cost entailed in the maintenance of milling cutters, &c., but even when this has been taken into consideration, together with the fact that these special tools are often more delicate than the old-fashioned tools, yet their accuracy and capacity for largely increased output more than makes up for these. and, generally speaking, the examples given show a net gain of at least 50 per cent. The cost of planing has been greatly reduced, quite 20 per cent. in many cases, by the introduction of the 4 to 1 return machine, and the use of a boring and turning mill, even on general work, will frequently save 25 per cent. over the lathe.

Shop Order No.

Date Rec'd.

Date Comp'd.

Week ending.	Time.	Labour	Materials	Total for Week.	Total.	Remarks.

FIG. 13.—SIMPLE FORM OF TIME-SHEET.

Fig. 11 illustrates a handle turned from the solid bar (about ⅔ full size), and finished with a highly polished surface, all done in an automatic screwing machine at a cost of 1-10th of a penny each (ten a penny) for machining. The following striking examples of actual saving effected by the use of modern machines are given below; the reference to what was done formerly indicates a period not very long ago, so comparatively recent has been the development, or, at any rate, the general application, of automatic machines.

As already pointed out, great saving has been effected in machine work and labour by turning from the solid bar, but from this gain must be deducted slight loss in greater waste of material. For instance, take a job of making say 1,000 1¼ steel bolts 5 ins. long, cut from the solid bar. These can now be made at the rate of two to three per hour, and costing on piece-work 2½*d.* each for machining. Formerly it took a turner 1½ hours, and smith 1 hour, to do the same work. Again, a boy will make 300 to 400 small brass pins per hour (say 130 gross per week) on an automatic machine, and at the cost of ·37 of a penny per gross, as against 10*d.* per gross formerly. Or, again, 12 valve covers, formerly requiring 45 minutes to machine, can now be done in ten minutes. Condenser ferrules, formerly produced at the rate of 5 per hour, can

PROGRESS SHEET

Order No 1681

HP 1	Reduction	A	B	C	D	E	R
13	600 – 35	24	52	52	31	38	17·1

Week ending June 21st 1900

Shop Name	No	Pattern P	Pattern S	Saw	Wt in Rough	Lathe Rough	Lathe Finish	Drill	Plane	Gear Cut	Wt Finish
AG274	1	■									
BG269	2										
DG270	2										
CG271	1										
EG272	1										
G 273	1										
G 274	2	■	■		4						
G 275	1	■	■		7		◤				
G 276	1	■	■		7¾						
G 277	1										
G 278	1										
1	1			■	2½						
2	4										
3	1			■	½		◤				
4	2										
5	2										
6	1										
7	—										
8	1			■	14						
X72	1										
X 73	1										
20	1										
21	1										

	£		
Cost of Material to date	2	11	2
" " Labour " "	1	0	9

FEILDEN No 2251

FIG. 14.—SAMPLE OF PROGRESS SHEET.

now be turned out at the rate of 18 per hour. Also six ½-in. cock plates can be machined in 1¼ hours, which formerly took 7 hours. Six ½-in. cylinder covers can be machined now in 2¾ hours, which formerly took 5½ hours.

Many other examples might be given of what great saving is being effected by modern machining.

SUBSTITUTION OF ONE TYPE OF MACHINE FOR ANOTHER.

Prominent amongst the changes that have taken place in the modern machine shop is the substitution of one class of machine for others for operating on similar work, and it is the proper selection of the right tool for the job that denotes the capable foreman or manager. Then again, a tool that is adapted to economically turn out very large quantities of a similar article is frequently not nearly so economical when used for producing only a few pieces alike. For instance, it has been found in practice that studs can be made in small quantities in a chasing lathe fitted with a geometric head more economically and as quickly as an automatic screwing machine; but when the quantity reaches a certain limit, the automatic screwing machine becomes far cheaper. Again, the milling machine has largely supplanted the planer, and especially the shaper, for certain classes of work. Fig. 12 is a very good example of what is meant. This illustration shows a Universal Miller operating with a gang of cutters on seven surfaces at once. This class of work was formerly done in a planer or shaper, but the miller does it more cheaply, and, what is equally important, secures an accuracy never possible in a shaper or planer; for repetition work and for making parts to gauge, this method is ideal since very little is required of the operator beyond simple adjustment in the first piece, and maintenance of the

FIG. 15.—INTERNAL LIMIT GAUGE.

FIG. 16.—INSIDE AND OUTSIDE SCREW GAUGE.

cutters in good condition, the latter requirement being secured in the tool room. In many instances surfaces may be most easily reduced by a combination of the planer and miller, careful judgment being required to determine the most economical tool to be used. Circular milling and profiling, together with keyway cutting on a key seater has taken much work from the slotting machine which, however, still remains a useful tool. The ordinary lathe, the most important and perhaps most universal tool we have, has had its duties much reduced of late. At one time it was expected to do almost everything. Besides ordinary turning, facing, screw-cutting, and boring, it was expected to do, and did, most of the work that is now performed on special lathes, boring mills, screwing machines, surface grinders, etc., and it will always remain indispensable, its value being by no means decreased because its adaptations are somewhat restricted. A tool that has permanently come to the front of late, and has effected great saving, on account of the facility it offers for chucking and centring is the vertical lathe or boring mill. Few of these machines are to be picked up second hand, and they are one of the last to become idle in any shop. When fitted either with one fixed and one revolving spindle, or the two motions provided in a single ram, they offer opportunities for turning out work far more rapidly and cheaply than can be accomplished on the lathe, and their universal application is only a question of time—in fact, few works of any importance are now without some of them.

WAGE AND PROGRESS SHEETS, TIME RECORDERS, &c.

Great attention is now being directed to various methods of recording the time occupied on each job, etc. In fact, the systems adopted are almost legion, since each class of work requires different arrangement, and every large works, again, will have a number of different sheets in its various departments. This system of tabulating and recording is undoubtedly a means of reducing cost of production, besides giving important records, and it is of course entirely necessary with piece and bonus work. As likely to prove interesting, three different types of sheets are illustrated. Fig. 13 shows a simple form of sheet for the purpose of recording cost per week in labour and materials on any job or part of a job. Fig. 14 illustrates a somewhat novel form of progress sheet, lately introduced into a works making a well-known speed reducing gear for electric motors and other forms of driving. The object of the sheet is to indicate at a glance to the manager at the works, or the principal, when away, the progress made in any particular week. Referring to the diagram, a space on the top left-hand corner contains the h.p. which the gear will transmit: in this instance 13 h.p. On the same line is seen the reduction, that is, from 600 revs. to 35 revs., a reduction of 17 to 1, as seen in the last column, whilst the figures A, B, C, etc., indicate the number of teeth in the various wheels used. The column under No. denotes the number of wheels or pieces of a like kind. The letters P and S under pattern mean pattern shop and foundry, and the other headings explain themselves. The answer to the puzzle (as which it may appear) is this: The black square denotes the progress made on any part, for instance, take G 275, it will be seen that the work has passed through both the pattern shop and foundry, and is already in the lathe, and practically half finished, so far as that tool is concerned. Again, take

No. 3 of first column. This piece is not a casting, but a wrought or steel bar, forming one of the pins or axles; this has been sawn off, and is also half finished in the lathe, and so on. At the bottom is seen the cost of materials and labour to date on this particular set of reduction gear. This sheet, by its degree of blackness, enables the principal or manager to see at a glance the exact progress of any particular gear, and moreover enables them to detect whether the figures at the bottom bear the proper relation to the progress made, as compared with similar wheels and parts of a like size of gear.

Many other sheets might be shown, but all that it is desired to indicate here is that in details such as these, as well as improvements effected in machinery, it is sought to reduce cost of production.

ELECTRIC DRIVING AND HIGH SPEEDS.

The writer has always been a strong advocate (and at a time before it enjoyed the popularity it is now attaining) of electric motor driving. The systems adopted are two: (1) either to drive line shafting by motors; or (2) to drive each machine with a separate motor, thus dispensing with overhead gears and line shafting as far as possible. One, or a combination, of these systems is certain to become very general before long. Our leading manufacturers mostly favour the first system, although they also admit that the large machines can be advantageously driven by a separate motor. One of the difficulties associated with motor-driving under the second plan, and especially when using small motors running at a high speed, is the question of reduction and variation of speed. As is well known, most forms of motors, whether electrical or otherwise, are most efficient at one speed or within a limited range, and any great deviation produces considerable loss of efficiency. In the writer's opinion, however, it is only a question of time when the great advantage of what may be termed the localising of the application of power by having each machine self-contained and separately driven by its own motor, will be so fully appreciated as to stimulate our electrical engineers to supply us with a motor which will answer to the requirements of the mechanical engineer. It is only a few years ago that the electrical transmission of power through a distance of, say, 150 yards, was done at a loss of something like 30 per cent., whilst under 5 per cent. will now cover it. So that it is not unreasonable to suppose that as great an advance will be made in its application to driving machines. Whilst the system is much more expensive in first cost, the cost of working is less, and the increased facilities offered in the shape of convenience are rapidly becoming appreciated.

The following information was given to the writer by a large firm making extensive use of electrical driving. They consider

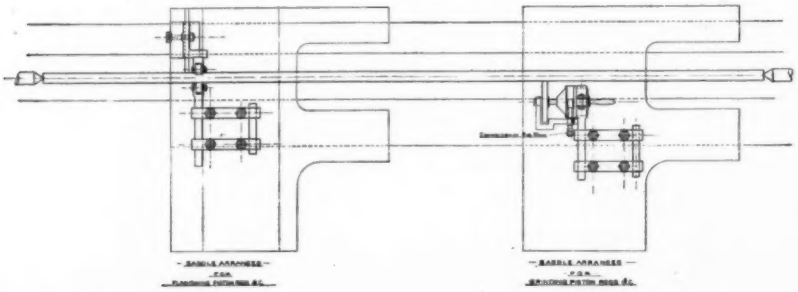


FIG. 27.—ILLUSTRATING THE APPLICATION OF A PNEUMATIC MOTOR TO AN ORDINARY LATHE FOR THE PURPOSE OF GRINDING LONG RODS.

that in all ordinary cases where tools are properly arranged, it is advisable to drive the machines in sections; but where large tools are in question, which may probably have to run overtime or night shifts when other adjacent machines are standing, they would advise independent motors. Where there are a large number of small motors, a greater amount of attention, repair, etc., is necessary, and the efficiency is not so good as where fewer and larger machines are in use. As regards the general efficiency of electric driving *versus* the ordinary line shaft driving, from engine to shaft, their own experience is that it would have been impossible to do the amount of work they are now doing on the old system. Probably the old arrangement was a bad one, but still, that would apply to nine establishments out of ten. Another opinion on this point, and one based on the present-day experiences of an up-to-date machine tool builder, proposes the use of medium speed multipolar motors, of not less than 15 h.p., and driving one, two, or three shafts, as the case may be. Whilst admitting that there are good arguments in favour of using a separate motor for each machine, they consider that, except in the case of shops using a number of heavy tools, the cost would be prohibitive. One of the greatest advantages they derive from electric driving, is the driving of tools whilst being tested. The shop in which the tools are tested has a false wood floor about five feet above the ground level, and the transmission of cables to various parts of the shop is a very simple matter. The motors for this purpose are 8 h.p. each, and are secured to the floor, wherever required, by coach screws. Apart from the advantages and saving already indicated, the opportunity presents itself, under this system, for taking exact readings of the power consumed by each machine. This will not only cause considerable surprise, but will lead to a lot of useful data being obtained in many ways. It is also especially valuable when it is desired to ascertain the h.p. required to drive any new machine, and enables makers to inform their clients the power they have to provide for driving such machine. In addition to the driving of fixed machines, electricity is receiving very extended application in respect to portable machines of the type of the Pneumatic Tool, and for some purposes competes very favourably with the air-driven machine. A firm who are making a speciality of electric driven tools, informs the writer that they have recently built a number of very successful portable multiple drilling machines, arranged to travel on rails on ground level, the motor taking the current by trolley pulley on fishing rod from overhead wire.

HIGH SPEEDS.

The tendency now-a-days is towards high speeds; line shafting is being driven faster, which permits of lighter shafts being used, and this, of course, also lightens the brackets, hangers, etc. Again, it is found that a light belt with a good speed is more efficient than a wide belt at a slower speed, while the strain on the motor shaft is much reduced.

PNEUMATIC TOOLS AND APPLIANCES.

The question of pneumatic tools has already been fully dealt with by the writer, both in this magazine * and elsewhere, but no article on modern workshop practice would be complete without some reference to them, since they have effected a complete revolution in certain classes of work. They are essentially labour savers, and, as time goes on, they are, in the writer's opinion, likely to find an application in every branch of engineering. They appealed first most strongly to the locomotive and ship builder, but machine-tool engineers and other manufacturers are now introducing these for the purpose of chipping, drilling, lifting, and moulding, etc. It is of course desirable that standing expenses in relation to work turned out should be as small as possible; in other words, the quicker a job can be got out of a shop the cheaper it is produced. The saving thus effected by the application of pneumatic tools is especially noticeable in connection with caulking and riveting boilers and ships. For instance, a boiler-flue that formerly

* See articles on "Pneumatic Tools and Appliances," by Ewart C. Amos, M.I.Mech.E., in this magazine, Dec. 1899 to Sept. 1900.

took eight to ten days to caulk by hand can now be caulked in ten hours with a pneumatic caulker. The cost of pneumatic caulking and riveting is about half that by hand caulking, and, in addition, there is the saving effected by getting the work out of the way, less space being required. Another instance where hand labour is rapidly being supplanted by the pneumatic tool is in flue rolling and tapping tube plates. In respect to the former, by using an air-drill to rotate the expander, a $1\frac{5}{8}$-in. diameter steel boiler tube can be expanded in 30 secs., as against eight to ten minutes by hand rolling. In regard to tapping the holes in locomotive fire-boxes, a pneumatic drill will pass a tap right through the inside and outside plate in 36 seconds as compared with 1 min. 48 sec. with a flexible shaft, or five or six minutes by hand. Rymering of holes in ship and bridge work has now become so simple and inexpensive (two men can rymer 2000 holes per day) that the hand drift is largely being dispensed with, and the result is in all respects far more satisfactory. These and many other instances might be given showing the great saving effected by their use over hand labour. In addition to actually doing the work quicker, they enable steel castings to be advantageously used where previously forged work was necessary, owing to the difficulty of hand-drilling the harder metal. Again, modern practice demands, and especially in those works where piece or premium work is in vogue, that every facility shall be given for the easy and rapid handling of work, either from shop to shop and from shop floor to machine. By the use of the pneumatic hoist work is rapidly raised and lowered or adjusted on the lathe or other tool, and by a system of overhead travelling hoists is also rapidly conveyed through the shops.

GAUGES, JIGS, AND TEMPLATES.

These are now indispensable, and, indeed, are daily receiving increased application in all modern shops. Besides the use of exact gauges, which are generally used for setting and testing, the limit gauge is growing very popular. An internal limit gauge is shown by Fig. 15. This type is for the purpose of measuring inside cylindrical holes. One end must "go in," and the other must "not go in." The difference in diameter of the two ends of the gauges represents the permitted variation in the sizes of the whole; the ends are of different lengths, so as to be quickly distinguished by the workmen. The actual difference, whilst quite appreciable to the sense of feeling, is only ·0012 above, and ·0004 below the dead size. In connection with these gauges it is frequently the practice to use hardened and ground arbors, which will, of course, always fit so long as the limit gauges are worked to. Fig. 16 shows an inside and outside screw gauge. Besides ensuring great accuracy, the use of limit and other modern systems of gauges, of which there are many kinds, also cheapens cost of production when fitting parts, since without the use of them heavy pieces have frequently to be transported to the turning and grinding department and pieces individually fitted.

Jigs and Templates.—These are frequently as important as the machine on which they may be used, and, like the equipment of a milling machine, are often more costly than the machine itself. They are however largely indispensable where repetition work is done, and frequently make an ordinary machine nearly as efficient as an automatic one.

HARDENING, GRINDING AND FINISHING.

Probably the development and application of the modern grinding machine has helped as much as anything in changing shop methods. It is true that emery grinders have been in use for many years, but they are very different from the modern grinding machines. Besides greatly increasing the accuracy of modern machine-tools they have been largely instrumental in reducing the cost of production. Both for flat surface or cylindrical work there is nothing to approach grinding for producing accurate and finely-finished surfaces, and now that the cost of these machines has been brought within the reach of all tool-makers none can now afford to be without such machines. The question of hardening finished parts has

now been rendered very simple, not only by the introduction of handy and easily-controlled gas furnaces, but also because it is now an easy matter to grind after hardening. In the past many parts were not hardened, simply because of the difficulties presented in the absence of proper furnaces, and also because the parts were apt to warp in the process of hardening, and few firms possessed suitable grinders. The question of polishing also comes in here, as by means of the grinder hardened surfaces can be left as bright and as highly finished as before hardening. Again, the use of drawn rods and bars, which are now supplied true to $\frac{1}{2000}$th part of an inch, and are therefore fit for use without any machining for a number of purposes, can, with the use of the grinder, be rendered absolutely true. In connection with the grinding of long pistons and other rods, and where it is not desired to go to the expense of a large grinder, an illustration is given in Fig. 17 of how an ordinary lathe may be utilised for this purpose. The piston rods in question were 16 ft. long. The drawing shows two saddles, one carrying a planisher consisting of three rollers mounted in a holder held in the tool rest, whilst the other saddle carries a pneumatic motor, on the spindle of which is fitted an emery wheel. In actual practice, however, only one saddle is used, and the planisher is placed on the same rest as the motor, and acts as a stay, and ensures that the rod does not spring away from the emery wheel. By means of grinders, cutters and tools can now be finished to precise angles by unskilled operators, and the modern grinding machine, although still somewhat expensive, is an indispensable tool where economy in production and high-class finish is required.

FOUNDRY IMPROVEMENTS.

Not the least important, although not infrequently the least considered department, from the economical point of view, is the Foundry. This, of course, is a distinct department, but bears considerable relationship to the cost of the finished article.

The American machine-tool castings possess, on the whole, a far better surface, and are more accurate than our own. Probably greater care is taken in the moulding and in the selection of the raw material.

The advantages accruing from the use of moulding machines, such as the Tabor Pneumatic Machine, Samuelson's, and others, is rapidly being appreciated in connection with repetition work. The pneumatic hoist and other modern appliances are all uniting in helping this department to do its part in the way of helping to reduce cost of production.

WORKSHOP EQUIPMENT.

Apart from the question of saving effected by improvements in individual tools, methods, and systems, there is also the general question of the equipment of a shop as a whole. It is, of course, very advantageous to improve in any particular department, but the highest efficiency can only be obtained by bringing all up to date, and this is a point that cannot be too strongly insisted upon. The writer, when inspecting various works from time to time, has often been struck with the obsolete methods adopted in driving the plant, itself perhaps quite up to date; or one frequently finds good tools, but without a tool-room. Again, the various shops may be fairly up to date, but a visit to the engine-room discloses a condition of things that has very little regard for economy in fuel consumption. Anything that will turn the main shaft round seems to satisfy at many works, and this state of things is not confined to this country. Increase in the price of coal and the introduction of electric driving is, however, helping to produce satisfactory changes. In existing works the best arrangement of shops as demanded by modern practice is frequently impossible, except at great cost; but in new ones the following features will probably exist, and will be common to most shops, irrespective of the kind of goods manufactured:—

A foundry, having plenty of light and head room, and fitted with electric cranes in combination with pneumatic hoists capable of feeding the whole area; moulding machines, etc., for repetition work.

A store-room for finished parts or parts in process of manufacture.

A tool-room, to be placed as nearly as possible in the centre of the building, and therefore equally accessible to all parts; such room, if possible, to be in communication with all the various floors or departments by some mechanical device for conveyance of tools.

A separate room in which castings can be stored especially for standard and repetition work.

A gear and rack-cutting department, which should include a bevel-gear cutter.

A separate grinding and polishing department.

A cutting off and centring department adjacent to the smith's shop.

A hardening and tempering department.

Transmission of power on the electric systems described in this article, and where shafting exists self-oiling and self-aligning bearings are essential.

A well-lighted and spacious drawing office is necessary in all works.

Omission is made of some of the machine shops, etc., as these will of course include planing, turning, drilling, etc. In most shops the milling and boring departments now occupy very important places.

All these various departments must be provided with ample means in the shape of quick travelling electric cranes, pneumatic hoists (both of the stationary and travelling types) tram lines for the easy transportation of parts and machines from one department to another, or to and from the tools by which they are machined.

This brief description is not intended to more than suggest some of the requirements of a modern works.

COMMERCIAL MANAGEMENT.

Whatever attempts may be made in the shops for the reduction of cost of production, their result will be largely minimised if care and up-to-date methods are not also employed in conducting what is essentially the commercial side of engineering. In this category may perhaps be included methods employed in keeping time and shop sheets, and accounts generally, the proper placing of the goods upon the market by suitable agents, attractive catalogues and discriminate advertising in the Press.

These and similar factors all join in determining whether a works shall be run at a profit or loss, and in the case of either, what that amount shall be.

CONCLUSION.

In conclusion the author is conscious of many omissions in his treatment of a subject at once difficult and involved, but trusts that some suggestions may prove useful and interesting.

This, the new century which we have just entered upon, is likely to see changes and improvements in engineering that will immeasurably surpass anything achieved in the Nineteenth Century just completed, great as were its developments, especially during the latter half. The indication of increased production on a large scale with a corresponding reduction of manual labour can have only one result, viz. increased luxury and ease. Whether it be for the good of the many or the few, will depend on whether capital and labour can adjust their differences; but it must be admitted that the outlook is decidedly more hopeful than at the commencement of the last century.

Railway Engineering.

By C. E. ALLEN, A.I.Mech.E.

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For the origin of railways we must look back far into the seventeenth century, when, in remote colliery districts of the North, coal-haulage was effected by wagons laboriously and slowly dragged along wooden tramroads by horses. From its origination in the early years of the century the practice spread, and wagon roads were laid down in Scotland and Wales. The little resistance offered to wear by, and the propensity to rot existing in, wooden rails, led to the adoption of plates of iron for protecting their upper surface, and from this it was but one step to a rail made entirely of iron. "Plate-ways," so called from the peculiar shape of these early cast-iron rails are, according to Smiles, supposed to have existed as early as 1738, although it is not until 1776 that we have a really authentic instance of an iron railway. The rails of this and other early tramroads were flanged on one side, the flange serving to keep the wheel from leaving the rail.

Thirteen years afterwards edge rails were introduced at Loughborough, the flange in this case being cast on the tyre of the wheel; this method proving the most advantageous, was soon widely adopted over most of the colliery districts.

While horse-power or the stationary steam-engine remained the only tractive power available for the haulage of wagons, no great development took place, or was indeed possible, in connection with tramways. It was the invention of the locomotive by Trevithick, and its perfecting by George Stephenson, that was to give a great impetus to the construction of iron roads, and place the question of steam locomotion on a successful basis. It is only when we hold steadily in view the position of railways to day, as compared with their humble origins of a century back, that we are enabled to realise how much we owe to the locomotive. Engineering works of a character and frequency never before dreamt of have been necessitated which, more than anything else, has raised the calling of a civil engineer into one of the most responsible and difficult of professions. The impetus that the introduction of steam locomotion on railways gave to trade and industry generally, and the important factor it has proved in the economic history of the century are sufficiently well recognised not to need any dilating upon here. The chief considerations in this article will therefore be the more important and interesting of the constructional engineering features that railway-making has necessitated.

The first railway in this country designed for the purpose of carrying both passengers and goods was projected by Edward Pease, between Stockton and Darlington, an Act of Parliament authorising the construction of the line being passed in April, 1821. This Act, however, provided for the use of horses and men as a tractive power, and it was not until 1823 that a further Act was obtained at the instigation of George Stephenson, the engineer of the company, whereby permission was granted to work the railway by means of locomotive engines, and, moreover, for the purpose of hauling passengers. Although no bridge, tunnel, or earthworks were necessitated on this line that call for mention, this length is of interest in that the question of gauge was practically determined in connection therewith. The gauge of the vehicles commonly employed on roads had been about 4 ft. 8½ ins., and in the construction of early tramways this measurement had been adopted. The question of utility rather than any theoretical or scientific considerations probably decided Stephenson in fixing on this gauge for the Stockton and Darlington Railway, as it is related that some of the earth wagons used during

construction were brought from an existing tramway, and that others were constructed to the same dimensions.

We owe, therefore, the universally adopted gauge of to-day perhaps to a fortuitous circumstance as, even if 4 ft. 8½ ins. had been found to be the safest and most economical gauge for road vehicles, it does not follow that the same consideration affecting its adoption would have equally applied to railways worked by steam. The intrepidity of Brunel, as will be seen, led him to challenge it, with what results are tolerably well-known, and which will be discussed later.

In view of the railway being worked by locomotives, the question of rails had also to be determined. Wooden rails were obviously out of the question, although in the Act of 1817 they had been contemplated. Those finally adopted were of malleable iron of the fish-bellied type. They weighed 28 lbs. to the yard, and were 2¼ ins. broad at the top, 2 ins. deep at the extremities, and 3¼ ins. deep in the central portion. They had an upper flange ¾ in. thick and cost about £12 per ton. A portion of the length was, however, laid with cast-iron rails to save expense. The railway, which consisted of a single line with four sidings to the mile, was opened in September 1827, and its immediate success led to the promotion of many similar projects all over the country.

The next line of importance calling for notice is the railway between Liverpool and Manchester, associated in the minds of most with the difficulties encountered in crossing Chat Moss, and the unfortunate death of Mr. Huskisson, one of the directors, on the opening ceremony which took place on September 15th, 1830. Eight years before this a project, for connecting these two important towns by a tramway for the rapid transit of goods, had been discussed, but a subsequent Bill was withdrawn.

The inaction of the Bridgewater Canal Company, upon whom the carriage of most of the traffic devolved, directed the attention of interested men to the absolute necessity of some improved mode of conveyance, and in 1826 a further Act was obtained, and works commenced under the direction and supervision of George Stephenson, the line of route adopted being somewhat different from his earlier survey made in conjunction with his son Robert.

The genius of George Stephenson is chiefly associated in the minds of the majority with his improvements in the steam locomotive, but a careful consideration of his life-work would show that his reputation is almost quite as deserving in connection with his work as a civil engineer.

It needed no small amount of courage and self-confidence to embark on an enterprise involving works of, for those days, such magnitude and difficulty as were necessitated in the construction of this railway, and to induce capitalists to place sufficient confidence in his principle, which has been substantially adhered to right through, viz. of making his railways as nearly level as possible, involving though it did an enormous expenditure in construction. The ruling gradient was fixed at 1 in 900, except for inclines in the vicinity of Rainhill, which were unavoidable, and for which special provision was made for years after, in the form of stationary engines; the gradients adopted for the London and Birmingham and the Great Western Railways were 1 in 330, and 1 in 1320 respectively for the greater part of the way. In later years, and with the increased strength of locomotives, the tendency was to introduce steeper gradients; for instance, Locke constructed lines having long lengths of 1 in 70 and 1 in 80, although the motive actuating him was probably to reduce the initial expenditure. In the Great Northern Railway, the tendency is to hark back to Stephenson's policy, as we find the ruling gradient of 1 in 200. It has, however, been found, especially in recent years, that steep gradients mean heavy locomotives, increased cost of motive power, light trains, and reduced speeds, and that associated with steep gradients are, generally speaking, frequent curves of short radius, which militate against fast and easy travelling.

As illustrating the loss of motive-power due to steep gradients, the following table, taken from Mr. W. H. Mill's excellent treatise on Railway Construction, is appended :—

	PASSENGER ENGINE: Six wheels, driving and trailing wheels coupled, 6 ft. 6 in. diam. Cylinders, 17 ft. × 24 ft. Locked-down pressure on safety-valves, 140 lbs. per sq. inch. Assumed pressure at cylinders, 120 lbs. per sq. inch. Weight of engine, 39 tons. ,, ,, tender, 24 ,, 63				GOODS ENGINE: Six wheels, all coupled, 4 ft. 6 ins. diam. Cylinders, 17 ft. × 24 ft. Locked-down pressure on safety-valves, 140 lbs. per sq. inch. Assumed pressure at cylinders, 120 lbs. per sq. inch. Weight of engine, 34 tons. ,, ,, tender, 24 ,, 58			
Assumed cut-off...	¼	⅓	½	¾	¼	⅓	½	¾
,, mean effective pressure, lbs.	45	56	76	100	45	56	76	100
,, tractive force ... lbs.	4000	4979	6758	8892	5780	7192	9760	12844
Speed in miles per hour	60	40	30	15	40	30	20	15
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Level	97	230	447	892	213	358	623	907
1 in 1000	84	196	373	707	187	310	532	768
,, 800	81	188	358	671	181	299	512	739
,, 600	76	177	335	618	172	285	482	695
,, 400	68	157	296	533	157	257	432	621
,, 300	60	141	263	467	143	233	390	560
,, 250	55	129	241	424	133	216	361	519
,, 200	47	114	213	372	120	195	324	467
,, 150	37	93	177	304	101	165	276	397
,, 100	21	63	126	217	74	123	208	302
,, 90	...	56	114	197	...	113	191	279
,, 80	...	48	101	175	...	101	172	253
,, 75	...	43	94	164	...	95	163	240
,, 70	...	39	86	152	...	88	153	226
,, 60	...	28	70	128	...	74	131	196
,, 50	...	...	53	101	...	...	107	163
,, 40	...	...	...	73	...	...	...	127
,, 25	...	...	...	27	...	...	...	67

Hence, in the most recently constructed trunk line, viz. the Great Central Extension to London, specially laid out to accommodate high speeds, the gradients are good, the steepest being 1 in 130 north of Nottingham, and, with the exception of two short lengths, 1 in 176 between that town and Rugby. To extend Stephenson's policy south of Rugby entailed what it did in early days, viz. heavy earthworks in cutting through the ridges and embanking the valleys. Cuttings and embankments, as in the case of the London and Birmingham Railway, of over fifty feet in depth and height respectively were of frequent occurrence, and in one case where the ridge was of unusual height a tunnel of 3,000 yards. The difficulty of crossing such a country economically was increased by the fact that the *maximum* gradient allowed south of Rugby was 1 in 176, and the minimum curve sixty chains in radius, and that in one case only, the normal curve being one mile radius. The writer has endeavoured to obtain from the company the figures showing the cost of the works, with the idea of instituting a comparison between the earlier lines constructed by Stephenson, but without success. It is safe to assume, however, that the cost must have been heavy, as it must always be where severe restrictions, imposed by the resolve to follow Stephenson's policy, are insisted upon, viz. to secure a first-class running line. There are other considerations leading to the correctness of the

SOUTH FACE OF THE TUNNEL UNDER PRIMROSE HILL, LONDON AND BIRMINGHAM RAILWAY.

policy of the pioneer of railway engineering, such as, for instance, the additional cost involved, where steep gradients are adopted, in laying down a road-bed of the most substantial character, a strong permanent way, maintenance, heavy wear and tear caused by skidding wheels and brake action, bank engines, and in some cases additional brake-power and a staff of brakesmen.

If further evidence were wanting as to the correctness of the principles of the older engineers we could with Mr. Acworth, point to the North Western holding its own against all rivals, and to the Great Western Railway competing successfully for the Exeter traffic in spite of their line being over twenty miles further than the rival route. Living as they did to see locomotives constructed that could haul trains over such gradients as the Shap summit, 1 in 75 for 4 miles, the Beattock 1 in 80 for 10 miles, the Lickey incline 1 in 37 for 2 miles, the earlier engineers saw in this no reason to recommend cheaper and more difficult running lines. Modern practice confirms their view, and we to-day see the Midland Railway company, possibly having met with anything but a satisfactory experience in connection with the Licky incline, spending a huge sum of money in constructing a short length of main line, involving a tunnel 3,866 yards in length, and an expensive girder bridge over the Mersey to save a mile or two of steep gradients into Manchester.

Having attempted to justify the policy of the elder Stephenson, let us return to the Manchester and Liverpool Railway, where the chief difficulty was tackled first, namely, the crossing of the Chat Moss.

This is an immense bog of peat, spongy and semi-fluid in character, rising above the level of the surrounding country. Owing to the nature of its composition it swells considerably in rainy weather, and attempts made by the engineers to drain it proved unsuccessful, the drains filling up almost as fast as they were cut.

Other engineers pronouncing it impossible to be compassed, Stephenson conceived the idea of crossing it by means of a floating bearing surface composed of sleepers, the underlying semi-fluid mass

being thickened by depositing a mass of tree branches and hedge cuttings covered with gravel, double thicknesses of hurdles being further utilised where the ground was softest. In the central portions, empty barrels fastened end to end and covered with clay were used successfully to drain some portion of the fluid exudation. An embankment at the Manchester end of the bog gave the greatest trouble, as the increasing weight caused the materials to disappear; filling in with dry moss was resorted to, but it was not until 670,000 cub. yds. of moss had been tipped that a satisfactory bearing road was rendered possible.

Another heavy work necessitated on this line was the Mount Olive cutting in solid rock two miles long, and in some parts 80 ft. in depth, and from which 480,000 cubic yards of stone were removed. What in those days was considered to be a fine piece of work was the Sankey Viaduct, built at a cost of £45,000, consisting of nine arches each of 50 ft. span, rising 70 ft. from the ground level. It was constructed of brickwork and faced with stone, piles being driven to form foundation supports for the piers. In all 63 bridges were constructed in the 30 miles, brick arches being used except in cases where the headway was limited, when simple cast-iron girders were used probably for the first time in bridge-work.

The railway over embankments was flanked with earthbanks properly sodded—a plan, not followed in railways of a more recent date—adopted to check the progress of an engine which had left the rails.

The permanent way was laid partly with double-parallel rails weighing 75 lbs. to the lineal yard, and partly with 50-lb. fish-bellied rails. The estimate for the works was £510,000, but up to June, 1840, the total sum expended was £1,407,172.

Our chief consideration being the constructional portion of railway work, we will not enter into details of the historic locomotive contest at Rainhill that resulted in the victory of the "Rocket," a circumstance which settled for good the triumph of the locomotive as a tractive power.

The next line to be considered is that which has been aptly described as the

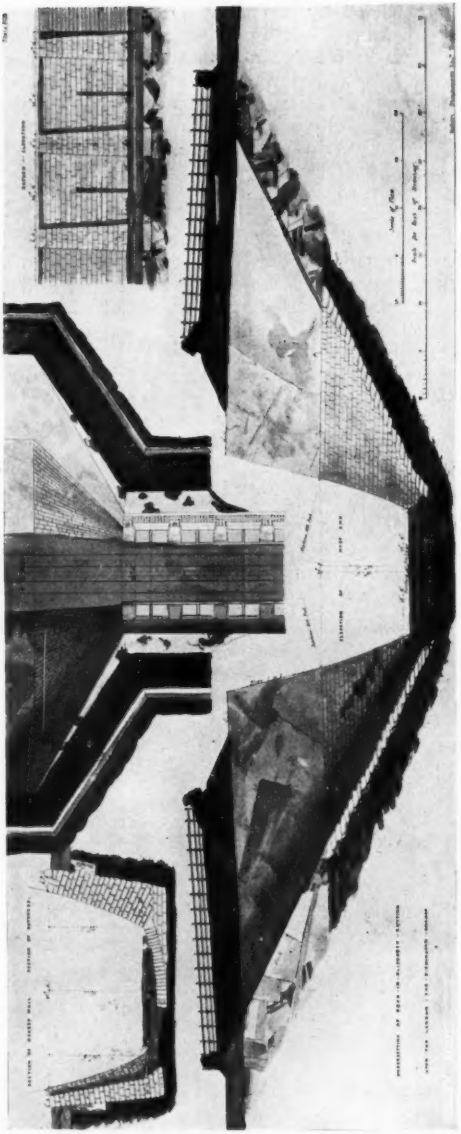
ENTRANCE TO BLISWORTH CUTTING, LONDON AND BIRMINGHAM RAILWAY.

"monumental" railway, by reason of the solidity and magnitude of the structures necessitated, a railway which every young engineer would do well to study; we refer to the London and Birmingham Railway, surveyed by and constructed under the supervision of Robert Stephenson. The startling results obtained by the Stockton and Darlington and Liverpool and Manchester Railways opened the eyes of railway detractors, and the Bill passed both Houses without opposition; and when the great utility of the measure is remembered, this is nothing to be surprised at.

In the early days of railway engineering the data for an estimate in contract works were not arrived at with the same facility as they are to-day, and in mentioning that the estimate laid before Parliament for the construction of the 113 miles of way was £2,500,000, no surprise will be evinced when it is stated that no less than seven contracts were thrown on the company's hands.

The total cost of the undertaking eventually proved to be something over £5,000,000, or, taken at per mile, £47,376, and it is probable that an estimate for the same line taken at the current prices of to-day would not be less.

The completion of the London and Birmingham Railway marked a complete change in the public attitude towards railway undertakings, and in four or five years from that date the foundations of nearly all the leading trunk lines of the country had been laid. Bills were obtained for the construction of the London and Greenwich, London and Southampton, Birmingham and Derby, Eastern Counties, Bristol and Exeter, Great Western, Manchester and Leeds, Midland Counties, North Midland, South Eastern, London and Brighton, Birmingham and Manchester, and up to the year 1840 altogether 299 Acts,



UNDER-SETTING OF ROCK IN BLISWORTH CUTTING, LONDON AND BIRMINGHAM RAILWAY.

authorising the construction of 3,000 miles of railway, had been passed.

In considering the features of engineering interest on the London and Birmingham Railway, some mention must first be made of the massive Doric portico constituting the entrance to Euston station, a stately edifice which has become one of the landmarks of the metropolis; its unique character alone, in that, if, as far as we are aware, its example has not been imitated on any other line, would justify a passing reference. It extends for a width of 300 ft., and the columns, which have a diameter of 8 ft. 6 ins., rise to a height of 42 ft., or taking it to the apex of the pediment, 72 ft. In its construction 75,000 cub. ft. of Bramley Fall stone were used, some of the individual blocks weighing as much as 13 tons. The total cost was £35,000.

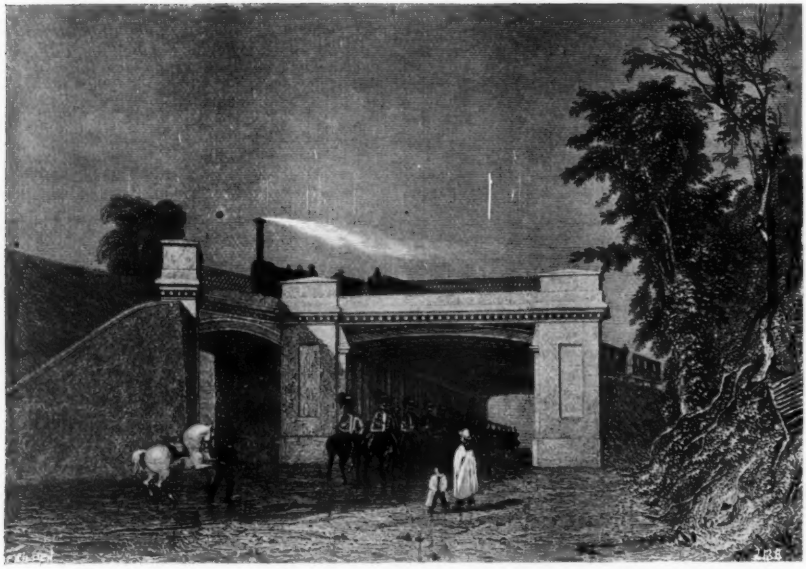
The tunnels necessitated on the railway possess features of interest, that under Primrose Hill, on account of the monumental and highly ornamental character of the south face, offering an example of a work combining at once elegance and utility, a combination not frequently met with in these days; Kilsby tunnel, on account of the difficulties met with and the perseverance shown by the engineer in overcoming them.

The handsome stone front of the Primrose Hill tunnel, referred to above, was erected from a design made by Stephenson's secretary; the tunnel itself is 1,100 yds. in length, 22 ft. in height and width, the ring three bricks thick, built in cement with a two-brick invert, stone springers being used throughout at the junction of the side walls and invert. The tunnel is ventilated by a single shaft.

METHOD OF EXCAVATION EMPLOYED IN THE TRING CUTTING, LONDON AND BIRMINGHAM RAILWAY (JUNE, 1837).

Watford tunnel, over 1,900 yards in length, runs through, in succession, chalk and loose gravel, in the former case a side wall only being necessary to support the arch, while in the latter an invert was built in. In section this tunnel is nearly semicircular, being 25 ft. high and 24 ft. wide, and in the course of construction six shafts were sunk.

Kilsby tunnel was a work which might



DENBIGH HALL BRIDGE, LONDON AND BIRMINGHAM RAILWAY, DESIGNED ON A PLAN TO AVOID THE NECESSITY OF CONSTRUCTING A LARGE OBLIQUE ARCH.

have been avoided, and so saved the company nearly £300,000 (it cost £125 per lineal yard), but for a foolish prejudice on the part of the inhabitants of the town of Northampton, who raised an opposition to the line passing through it.

This tunnel, which penetrates the Kilsby ridge, is 2,398 yds. in length, and is driven at a depth of 160 ft. below the surface. It is 30 ft. in height and 30 ft. wide, and has two air shafts 60 ft. wide, which were designed not only for constructive purposes and ventilation, but to admit a flood of light to enable the engine driver to see the rails throughout the whole length. The contract was originally let for the sum of £99,000, but in consequence of the difficulties arising in connection with a bed of quicksand, the tunnel was not completed for a sum less than £300,000.

In these early days of railway construction, when the powerful steam pumps that are now employed were as yet unthought of, the deluge of water that burst into the workings 200 yds. from the south end of the tunnel was of so formidable a character that the advisability of abandoning the operations was seriously considered.

It appears that the trial shafts which were sunk to determine the character of the ground beneath failed to reveal the existence of a bed of quicksand, which lay under a bed of clay 40 ft. thick, in consequence of which the water above-mentioned made its appearance, and in such quantities that the workmen were only saved by means of a raft. How the water was got under cannot be better described than in the words of Smiles.

The engineer found that there was nothing for it but to sink numerous additional shafts over the line of the tunnel at the points at which it crossed the quicksand, and endeavour to master the water by sheer force of engines and pumps. The engines erected possessed an aggregate force power of 160 horses, and they went on pumping for eight successive months, emptying out an almost incredible quantity of water. It was found that the water, with which the bed of sand extending over many miles, was charged was to a certain degree held back by the particles of the sand itself, and that it could only percolate through at a certain

average rate. It appeared in its flow to take a slanting direction to the suction of the pumps, the angle of inclination depending upon the fineness or coarseness of the sand and regulating the time of the flow. Hence the distribution of the pumping power at short intervals along the line of the tunnel had a much greater effect than the concentration of that power at any one spot. Protected by the pumps, the workmen proceeded with the building of the tunnel at numerous points. Every exertion was used to wall in the dangerous parts as quickly as possible, the excavators and bricklayers labouring night and day until the work was finished. The quantity of water pumped out of the sand-bed during eight months of incessant pumping averaged 2,000 gals. per minute, raised from an average depth of 120 ft. . . . The water pumped out of the tunnel while the work was in progress would be equivalent to the contents of the Thames at high-water between London and Woolwich.

Whilst on the subject of tunnels, it will be convenient in this place to look at works of this class of a more recent date existing on other railways.

The Box tunnel on the Great Western Line between Bath and Chippenham was the subject of much criticism at the time of its construction, and was another expensive and difficult work. It is the first on this line out of London, and could only have been dispensed with had a more circuitous route been adopted. It is $1\frac{7}{8}$ mls. in length, or 3,123 yds., and is driven about 70 ft. below the surface. It is ventilated by six shafts 30 ft. in diameter, and from 70 to 300 ft. deep. Where bricked the arch has six and the sides seven rings of brickwork, while the invert is composed of four rings.

The clear width at the level of the springing of the invert is 27 ft. 6 ins., and at 7 ft. 3 in. above this line it is 30 ft.; the clear height is 25 ft.; the foundation 36 ft. in width.

The list below shows the British tunnels exceeding one mile in length.

As years have gone on, the tendency to construct tunnels of greater length has become more frequent, in spite of the fact that some engineers, in contradistinction to the policy of the Stephensons, have not hesitated to adopt steeper gradients and

Name.	Railway.	Length.	
		Mls.	Yds.
Severn	Great Western	4	624
Totley	Midland	3	950
Standedge ...	London and North Western	3	62
Woodhead ...	Great Central	3	17
Bramhope ...	North Eastern	2	225
Medway	South Eastern	2	220
Festiniog	London and North Western	2	206
Cowburn	Midland	2	182
Sevenoaks ...	South Eastern	2	80
Rhondda	Rhondda and Swansea Bay...	1	1683
Morley	London and North Western	1	1590
Box	Great Western	1	1467
Catesby	Great Central	1	1240
Dove Holes ...	Midland	1	1227
Littleborough ...	Lancashire and Yorkshire	1	1177
Sapperton ...	Great Western	1	1040
Polehill	South Eastern	1	999
Mersey	Mersey	1	940
Bolsover	Lancashire, Derbyshire and East Coast ...	1	880
Bleamoor... ...	Midland	1	867
Queensbury ...	Great Northern	1	742
Kilsby	London and North Western	1	663
Shepherd's Well...	London, Chatham and Dover	1	572
Oxted	Brighton and South Eastern Joint	1	506
Wapping	London and North Western	1	490
Clayton	London, Brighton and South Coast ...	1	440
Sydenham ...	London and Chatham and Dover	1	440
Drewton	Hull and Barnsley	1	356
Greenock... ...	Caledonian	1	340
Bradway	Midland	1	264
Sough	Lancashire and Yorkshire	1	258
Abbott's Cliff ...	South Eastern	1	240
Corby	Midland	1	160
Honiton	London and South Western	1	121
Shambrook ...	Midland	1	100
Glaston	Midland	1	82
Merstham ...	London, Brighton and South Coast ...	1	70
Midford	London and South Western	1	53
Belsize	Midland	1	62
Glenfield	Midland	1	36
Claycross... ...	Midland	1	11
Harecastle ...	North Staffordshire	1	3

ONE OF THE FACES OF THE BOX TUNNEL, GREAT WESTERN RAILWAY. THE ADDITIONAL BRICK LINING WAS ADDED AFTER THE ABOLITION OF THE BROAD-GAUGE SYSTEM.

sharper curves. Hence, since the completion of the Box tunnel, 11 of greater length have been driven, culminating in the case of that under the River Severn, in a maximum length of 4 mls. 624 yds.

The tunnel under the estuary of the Severn was proposed as far back as 1871, and the contract was let and works commenced in 1873 by sinking a shaft 15 ft. in diameter, and lined with brickwork, near the Monmouthshire bank of the Severn, to the depth of 200 ft. The site selected is where the width of the estuary at high tide is about 2¼ miles, and at low-water the channel is 2½ furlongs in width the maximum depth of the estuary at high water being 95 ft. with a tidal rise of 37 ft. The total length of the tunnel is 4 mls. 624 yds.

A heading 7 ft. square was driven under the river from this shaft to drain the last part of the tunnel, and a second shaft connected to the first by a cross-heading contained the pumps for removing the water. A shaft was also sunk on the Gloucestershire side, and two shafts inland from the first were sunk on the Monmouthshire side. Headings were driven in both directions along the line of tunnel.

In October, 1879, a large spring was tapped, which flooded all the works which were in communication with the old shaft, and delayed the operations fourteen months, and involved the sinking of a new 18-ft. shaft and two shafts on the land side of the spring for additional pumping machinery.

The tunnel is lined throughout with vitrified brickwork, 2¼ ft. to 3 ft. thick, set in cement, and an invert 1½ ft. to 3 ft. thick has been added. The lining was commenced at the end of 1880; the headings under the river joined in September, 1881, and the last length of the tunnel completed August, 1885.

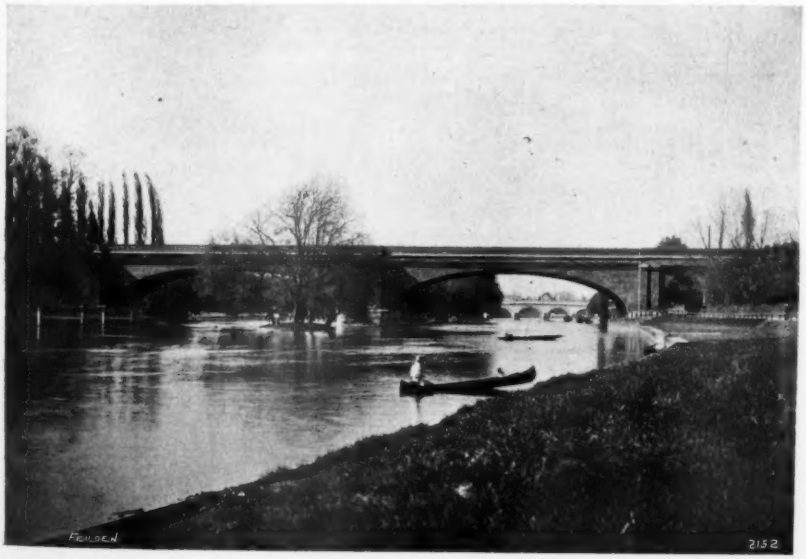
The tunnel is semicircular in section and 26 ft. in diameter; the arch was built first, then the invert was laid, and finally the side walls were built up. The tunnel was open for traffic in December, 1886.

The problem of piercing the Alps by means of a railway tunnel, where, in addition to the great length involved, the thickness of the superincumbent rock necessitated working from both ends without the use of intermediate shafts, presents features of peculiar interest. The following are particulars of the great tunnels now completed or in the course of construction :—

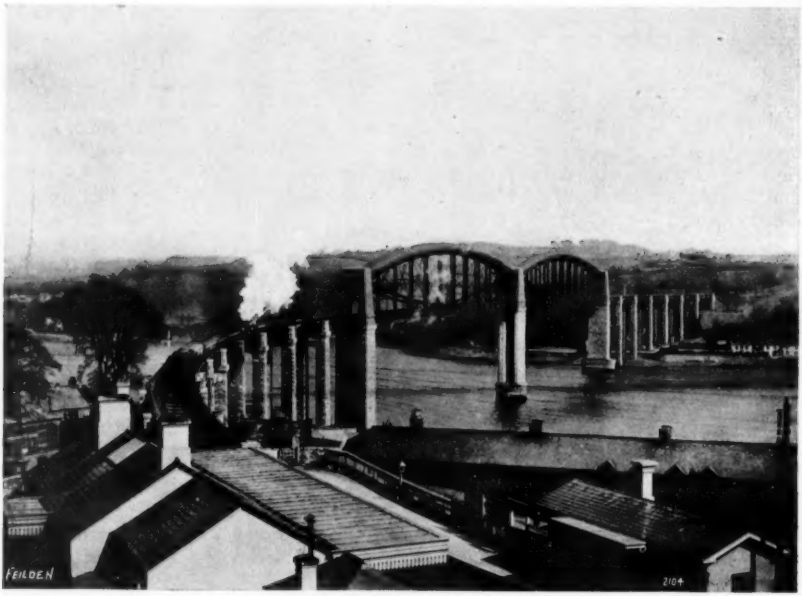
Tunnel.	Length.	Maximum height of mountain above the tunnel.	Progress per day.
Mont Cenis ...	$7\frac{9}{10}$ mls.	5420 ft.	2·57 yds.
St. Gothard ...	$9\frac{1}{4}$,,	5590 ,,	6·01 ,,
Arlberg	$6\frac{1}{4}$,,	2360 ,,	9·07 ,,
Simplon	$12\frac{1}{8}$,,	7000 ,,	5·5 ,,

The first blast was fired in connection with the Mont Cenis tunnel in 1857, and the comparatively slow progress made in the work is accounted for by the fact that mechanical drills worked by compressed air were not used until four years later. In 1871 the tunnel was opened for traffic, the total period occupied in construction being 14 years. It accommodates a double line of way, and is 20 ft. 6 ins. high, and has a width of 26 ft. ; and the whole length, with the exception of about 300 yards, is lined with brickwork or masonry. The gradients ascend from both ends—that on the French frontier side being 1 in 40 for a length of 47 kilos. —in consequence of which the smoke fails to get away, and in wet weather the platelayers find it impossible to work. To meet this difficulty refuges, every kilometre length, have been provided, where are stores of compressed air and water.

The St. Gothard tunnel, which, until the completion of the Simplon, will be the longest in the world, was commenced in 1872 and was opened for traffic nine years later. The method of working was by means of a top heading 8 ft. square, driven in advance. This was then enlarged in the direction of its length and the excavations continued to the invert level. Rock-drills, making 180 blows per minute, driven by compressed air, were used from the commencement, and from 13 to 18 holes of an average depth of



MAIDENHEAD BRIDGE, CARRYING THE GREAT WESTERN RAILWAY OVER THE RIVER THAMES: ONE OF THE FINEST EXAMPLES OF BRICKWORK EXTANT.



BRUNEL'S MASTERPIECE—THE ROYAL ALBERT BRIDGE, CARRYING THE GREAT WESTERN RAILWAY OVER THE RIVER TAMAR AT SALTASH.

3 ins. were driven by one machine in three or four hours, a similar period being required for the work of charging with dynamite, firing and cleaning up. Large volumes of compressed air were directed over the face of the work immediately after firing. Six hundred men, including the engineer and contractor, lost their lives during the construction, owing to the insufficient ventilation and the sudden change of temperature when emerging into the keen Alpine air. The problem of ventilation was here again a troublesome one, until a year or two back the Saccardo system of ventilation, whereby volumes of air are directed into the tunnel by means of a ventilating fan, was adopted. The application of this system reduces the temperature and frees the tunnel from smoke.

The Arlberg tunnel was commenced in 1880, and took little more than three years to complete. A bottom heading was driven, from which, at intervals varying from 25 to 70 yds., shafts were opened up, smaller headings being in turn driven from these to the right and left. The full section of the tunnel was then excavated and the masonry put in, each length of 8 yds. occupying about five weeks.

The Simplon tunnel, which is now in rapid course of construction, was fully described, with illustrations, in a recent number of FEILDEN'S MAGAZINE. This avenue will consist of two single-line tunnels running parallel to one another at a distance of 55 ft. apart from centre to centre. As in the case of the Arlberg works, a fine spray of water is injected after each blast, and thousands of cubic feet of air are thrown into the tunnel every minute. Other special arrangements have been made in order to prevent the recurrence of a mortality such as that which attended the driving of the St. Gothard tunnel.

The drills used were specially designed for the work by M. Brandt, whose recent

death the engineering world deeply deplores. The drill, illustrated in the last issue of FEILDEN'S MAGAZINE, is of the rotatory type and 3 ins. diameter, with a pressure on the cutting points of 10 tons, which, however, is capable of rapid reduction or augmentation. The works have now been proceeding for over two years, the number of lineal yards per day driven averaging 5·5, the time necessary to complete being estimated at 5½ years.

The following figures show the comparative cost per lineal yard of some of the principal tunnels:— Kilsby £125, St. Gothard £143, Arlberg £108, Mont Cenis £226, Simplon (estd.) £105, Box £100.

It will thus be seen that although the material at Kilsby consisted only of shale, the water-laden strata encountered brought up the cost per lineal mile to as much as tunnelling through the solid rock under the Alps. The same figures show, how with improved appliances the cost of tunnelling under circumstances practically the same has been reduced.

In this country the average cost of tunnelling could not be computed at less than £70 per lineal yard, while abroad it would average more owing to the difficulty of obtaining labour, materials, etc. In 1857, there were altogether 70 mls. of railway tunnelling in Great Britain, while to-day it would probably be not less than 125.

We have associated the consideration of the London and Birmingham Railway with a brief review of railway tunnelling, and we shall take the opportunity when dealing with the Great Western system of surveying the more important railway bridges that have been erected. One or two more points of interest, however, may yet be found on the London and Birmingham itself, and in particular may be selected the Blisworth cutting.

This cutting is one of the largest on the line, and was estimated to contain 800,000 cub. yds, but owing to the necessity of having to lengthen the widest part of it, the total quantity of material removed was 1,000,000 cub. yds. In length the cutting, which is in clay and limestone, is 1½ mls., with a maximum depth of 55 ft.

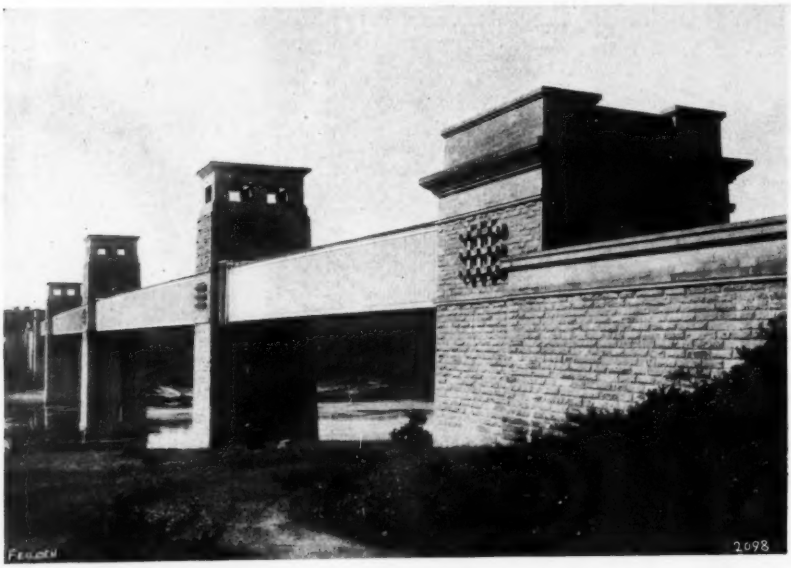
The clay and rock, existing in the pro-

THE HIGH-LEVEL BRIDGE AT NEWCASTLE, ONE OF THE GREATEST ENGINEERING ACHIEVEMENTS OF ROBERT STEPHENSON.

portions of about three to one, run in strata nearly parallel with the rails which are on an upward gradient from each end, and difficulties arose when the rock was found not to extend to the whole depth of the excavation, but that underneath it lay a bed of clay, 20 ft. thick, through which the rails had to be carried. To prevent any bulging out through the weight of the superincumbent mass, a rubble retaining wall averaging 20 ft. in height was built underneath the rock along the sides of the excavation. This wall was strengthened by buttresses at every 20 ft., supported by inverted arches built beneath the railway. At several points the rock was underset several feet, and a puddle-drain put in behind each wall with openings left at intervals to conduct the water to the side drains of the railway. An illustration (p. 156) reproduced from a copy of the original working drawing will make the above explanation clear.

The Tring cutting through the chalk ridge at Ivinghoe—the summit level of the railway—was responsible for 1,500,000 cub. yds. of material, which was run to spoil. In length it is 2½ mls., and averages 40 ft. in depth, with a quarter of a mile at 57 ft., and an illustration (p. 157) shows the method by which the material was removed in this and similar works before the introduction of steam navvies and excavators. It consisted in the employment of "horse-gins," by which the men were drawn up planks in a nearly perpendicular position by horses. A rope was attached to the front of the barrow containing the earth, the navvy supporting it by the handles, while both are drawn to the surface.

Another illustration (p. 158) of an interesting character shows the Denbigh Hall Bridge, an example of the ingenuity displayed by early engineers to avoid the necessity of erecting a very oblique arch. Upon the abutments and central support, which were extended far enough to allow the



THE BRITANNIA TUBULAR BRIDGE, CARRYING THE LONDON AND NORTH-WESTERN RAILWAY OVER THE MENAI STRAITS. IT WAS DESIGNED BY ROBERT STEPHENSON, BUT PROVED TOO COSTLY A STRUCTURE TO ADMIT OF IMITATION. IN SUBSEQUENT PRACTICE THE USE OF WEB-PLATES IN THE BOX-GIRDERS HAS BEEN ABANDONED IN FAVOUR OF LATTICE BRACING.

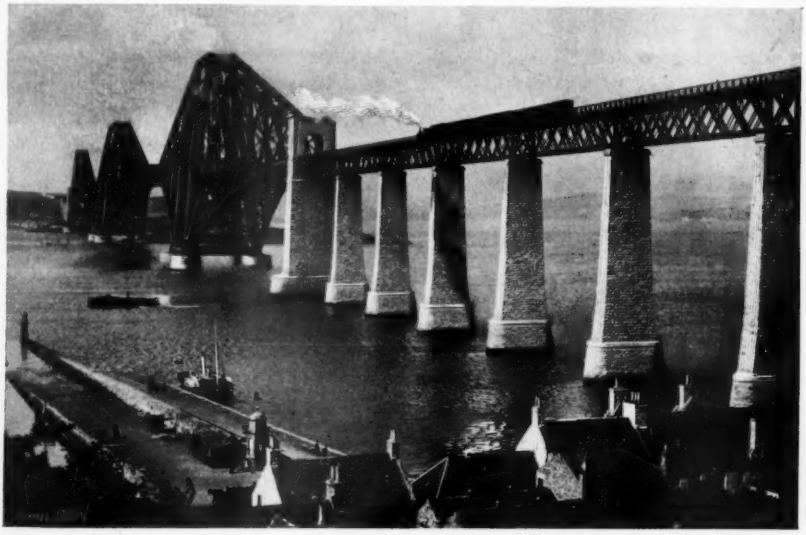
line to cross over obliquely, were laid very flat segmental iron ribs carrying the road.

Each end of the bridge is thus square with the roadway, and is of 34 ft. span, which would have been increased to 80 had a skew bridge been adopted. The total length of the bridge is about 200 ft., and the height from the road beneath to the soffit of the arch 20 ft.

The subsequent widening of the London and Birmingham Railway might afford an opportunity of many interesting comparisons being made between early and later practice, as for example at Bushey, where the original line is carried over the London Road by a viaduct of five arches of 43 ft. span each, with the central arch on the skew, altogether a magnificent example of brickwork, while the two later lines of way are carried by an iron plate-guide bridge of probably a less expensive character.

The introduction of cheap steel of good quality and high tensile strength has conduced more than anything else to the abandonment of brickwork in this country, although in America the latest practice seems to be in the direction of masonry arches, and moreover of such proportions and solidity as to cause a local editor to burst forth as follows :—

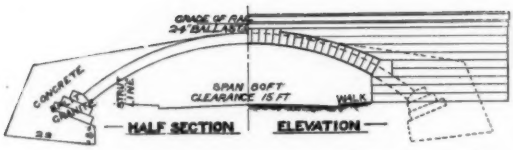
> How long before the arches will fall? There is nothing more durable than granite. Steel will corrode, but solid masonry will last forever. When the Brooklyn Bridge has tumbled from its piers, when the pyramids of Egypt shall have crumbled into dust, when Niagara shall have drained the Great Lakes, then shall our arches show signs of decay. If only the ravages of time work to destroy them, they shall remain forever majestic, massive, magnificent, durable and solid, the emblems of strength and character, and shall be a fitting and lasting memorial to co-operated, intelligent, well-directed labour.



THE FORTH BRIDGE—THE LARGEST AND MOST MAGNIFICENT STRUCTURE OF ITS KIND.

The accompanying drawing * shows the outline of foundations and the peculiarity of some of these arches which are replacing girder bridges in many of the American towns. The arch proper extends to the ground level, with the faces of the arch built up to a 7-ft. clearance on the street line, showing

* From a paper read by J. W. Rollins, Jun., before the New England Railway Club, May, 1900.



TYPE OF ARCH BEING ADOPTED IN AMERICA TO REPLACE GIRDER BRIDGES.

The arch proper extends to the ground level, and the peculiar method of construction saves considerable masonry.

a sort of buttress 4 ft. thick. The outside appearance of these arches is the same as that ordinarily seen, while this method of construction saves considerable masonry. The foundations were of concrete, 8 ft. below the finished street grade, and the pressure of the arch proper was distributed over this concrete foundation through three courses of heavy granite masonry under skew backs.

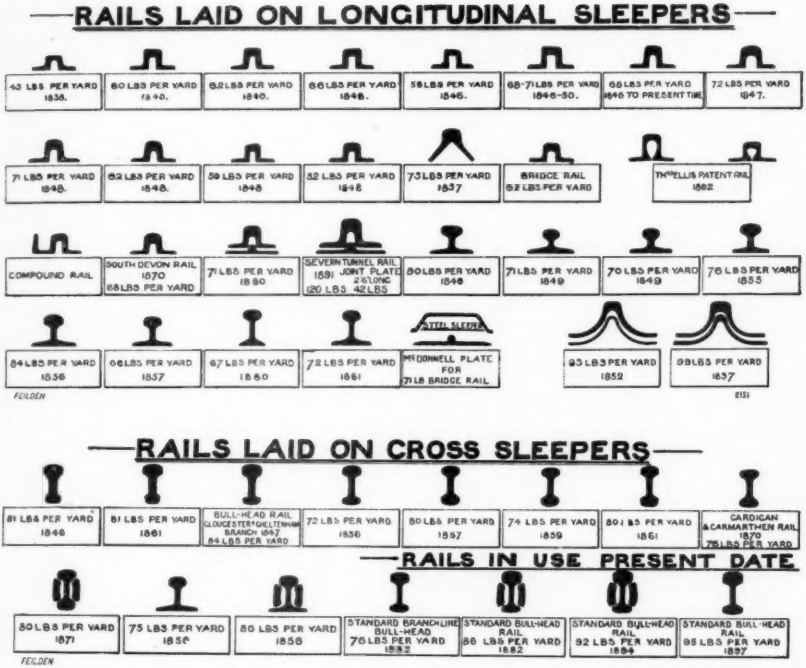
An interesting feature in recent English brickwork is the single-arch tunnel bridge peculiar to the northern division of the Great Central Railway. They have been constructed with spans up to 40 ft. and 45 ft., with about 10 ft. of bank on the top of the arch. In cases where the span is 45 ft., the rise of arch is 18 ft. The thickness at the crown for a width of 40 ft. is 2 ft. $7\frac{1}{2}$ ins., dropping to 2 ft. 3 ins. near the face. At the springing it is 3 ft. throughout. The length of arch is 73 ft. 6 ins., the spandril filling consisting of lime concrete, covered with brick on flat. Asphalte binds into this brick paving and makes a water-tight surface. The abutments were built with a thickness of 6 ft. $4\frac{1}{2}$ ins. at springing to 8 ft. $7\frac{1}{2}$ ins. over the footings, with six counterforts in each. The wings are constructed with a batter of 1 in 6, varying in thickness from 8 ft. 3 in. at the abutment end to 3 ft. $4\frac{1}{2}$ ins. at the newel.

The Great Western Railway, the *chef d'œuvre* of Isambard Kingdom Brunel, as the London and Birmingham was of Robert Stephenson, is associated with two important events in railway history, namely, the battle of the gauges and the atmospheric system. The former, after an existence of some twenty-five years, succumbed to the stress of competition; while the latter, interesting chiefly as an experiment, was abandoned after it had been in use for twelve months.

There is no reason to suspect that the 7 ft. $0\frac{1}{2}$ in. gauge adopted on the Great Western Railway by Brunel did not offer as great or even greater facilities for fast running than the 4 ft. $8\frac{1}{2}$ in. gauge which was destined to replace it; in fact, he claimed that travelling was quicker, although made at the same cost and with more ease than on the standard gauge railways, with a much less wear and tear of engines and carriages. Brunel also claimed that the expenses of construction were not dependent on the breadth of gauge unless the total width allowed for the loads or carriages was thereby, or for other reasons, increased, which was not necessary in consequence of a 7-ft. gauge; and, as a matter of fact, the London and Birmingham Railway could have been so laid without altering any of the works, although Brunel, in laying out the Great Western, made it 4 ft. wider at an increased expense of, including the cost of the land, from £300 to £500 per mile.

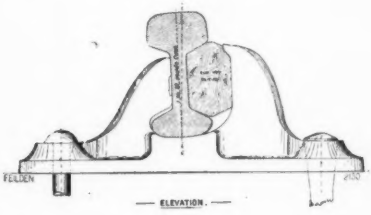
The break of gauges, and the consequent loss of facilities in traffic, were the factors which determined the abandonment of the broad gauge, although, as far as utility and efficiency are concerned, it more than held its own. Now that the dimensional limits of construction have probably been reached in rolling stock and locomotives, it is to be deplored that the 7-ft. gauge was not adopted as the standard on the grounds that an increased carrying capacity would have been insured at very little extra cost.

The Great Western Railway was opened to Maidenhead, a distance of 23 miles, in June, 1838; to Twyford in July, 1839; the whole length to Bristol being completed by June 30th, 1841. An important work is the Wharncliffe viaduct, which carries the line over the valley of the river Brent, near Hanwell. It consists of eight semi-elliptical arches, each of 70 ft. span, with a rise of 17 ft. 6 ins. The average height from the ground level is 65 ft. It is a fine example of brickwork, and is


RAILS LAID ON LONGITUDINAL SLEEPERS
43 LBS PER YARD 1838.
60 LBS PER YARD 1840.
62 LBS PER YARD 1840.
66 LBS PER YARD 1846.
56 LBS PER YARD 1846.
68-71 LBS PER YARD 1846-50.
68 LBS PER YARD 1846 TO PRESENT TIME
72 LBS PER YARD 1847.
71 LBS PER YARD 1848.
62 LBS PER YARD 1848.
59 LBS PER YARD 1848
52 LBS PER YARD 1848
73 LBS PER YARD 1837
BRIDGE RAIL 82 LBS PER YARD
THE ELLIS PATENT RAIL 1862
COMPOUND RAIL
SOUTH DEVON RAIL 1870 68 LBS PER YARD
71 LBS PER YARD 1880
SEVERN TUNNEL RAIL 1881 JOINT PLATE 2 OLONG 120 LBS 42 LBS
80 LBS PER YARD 1848
71 LBS PER YARD 1849
70 LBS PER YARD 1849
76 LBS PER YARD 1855
STEEL SLEEPER
84 LBS PER YARD 1856
66 LBS PER YARD 1857
67 LBS PER YARD 1860
72 LBS PER YARD 1861
McDONNELL PLATE FOR 71 LB BRIDGE RAIL
93 LBS PER YARD 1852
99 LBS PER YARD 1857
FELDEN
2151
RAILS LAID ON CROSS SLEEPERS
81 LBS PER YARD 1848
81 LBS PER YARD 1861
BULL-HEAD RAIL GLOUCESTER & CHELTENHAM BRANCH 1847 84 LBS PER YARD
72 LBS PER YARD 1856
80 LBS PER YARD 1857
74 LBS PER YARD 1859
80 LBS PER YARD 1861
CARDIGAN & CARMARTHEN RAIL 1870 75 LBS PER YARD
RAILS IN USE PRESENT DATE
80 LBS PER YARD 1871
75 LBS PER YARD 1856
80 LBS PER YARD 1856
STANDARD BRANCH LINE BULL-HEAD 76 LBS PER YARD 1882
STANDARD BULL-HEAD RAIL 86 LBS PER YARD 1882
STANDARD BULL-HEAD RAIL 92 LBS PER YARD 1884
STANDARD BULL-HEAD RAIL 98 LBS PER YARD 1897
FELDEN

GREAT WESTERN RAILWAY.—RAIL SECTIONS SHOWING DEVELOPMENT OF PERMANENT WAY.

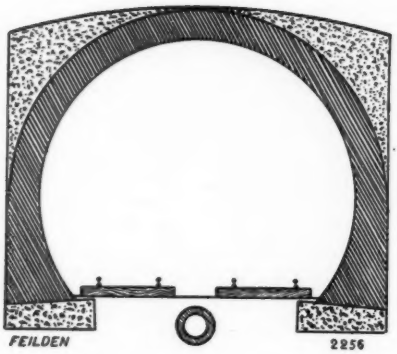
built throughout as light as possible, compatible with the most economical and effective distribution of material, a point to which Mr. Brunel paid the most profound attention. This principle in brickwork forms somewhat of a contrast to the method pursued in the earlier works of the Stephensons, whose fundamental policy was solidity. For example, in the case of retaining walls, Mr. Robert Stephenson adopted the curved form, relying upon its shape and massiveness to resist the forward pressure of the earth. On the other hand, Mr. Brunel's plan was, in such structures as were subjected to earth pressure from behind, to make them as light as possible, and, in the case of retaining walls, to adopt the straight form, introducing, however, at the back "sailing courses," which were in reality projecting shelves. The pressure of the earth on these courses increased the weight at the back of the wall; in other words, increased the resistance to forward pressure.*



RAIL AND CHAIR AS USED ON THE GREAT CENTRAL RAILWAY.

Perhaps the finest example of a brickwork structure is the bridge carrying the railway over the Thames at Maidenhead,

* For a detailed comparison of the two methods the reader is referred to the discussion following Sir B. Baker's paper on "Earthworks," read before the Institution of Civil Engineers, and reprinted in the *Transactions*, Vol. LXV.

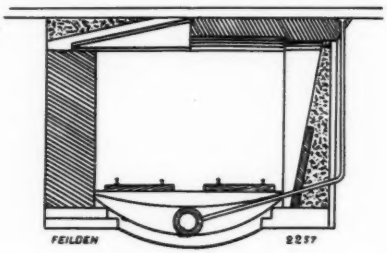


METROPOLITAN RAILWAY.—SECTION OF COVERED WAY.

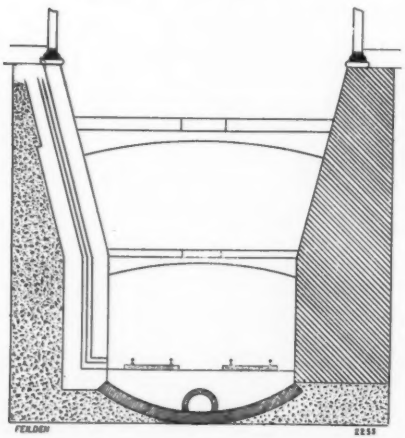
a view of which is given on p. 161. The bridge crosses the river, which is at this point about 290 ft. wide, in two spans of 128 ft., with a rise of 24 ft. 3 ins. Flood openings consisting of semicircular arches, one of 21 ft. span and three of 28 ft. span, precede and follow the main spans. The radius of curvature of the main arches, which are among the flattest ever built, is 165 ft., the line of pressure in each case being diverted in a downward direction by the thrust of the adjacent flat arches, which carry a mass of concrete.

During the construction, when the centering was slackened, the brickwork of one of the arches followed the centering for a distance of 5 ins. at about 15 ft. one ach side of the crown, and one of the spandril walls cracked, circumstances which at the time awakened the apprehensions of some with regard to the safety of the bridge. This, however, was remedied, and when the time came, years later, for the bridge to be widened, Sir John Fowler decided to carry the extra rails on brickwork, and by so doing preserved the elegance of the structure.

Many other of Mr. Brunel's brick and masonry bridges on this railway are of an interesting character, but space will not permit more than a mention being made of the three-arched gothic masonry bridge near Bristol, with a centre arch span of



METROPOLITAN RAILWAY.—SECTION OF COVERED WAY.



METROPOLITAN RAILWAY.—SECTION IN OPEN CUTTING.

100 ft.; the flying bridge near Weston-super-Mare, with a clear span of 110 ft., carrying a road across the line at 60 ft. above the rail level; bridges of the same character used to keep apart the sides of a cutting; and skew ashlar masonry bridges with mechanically correct spiral tapering courses.

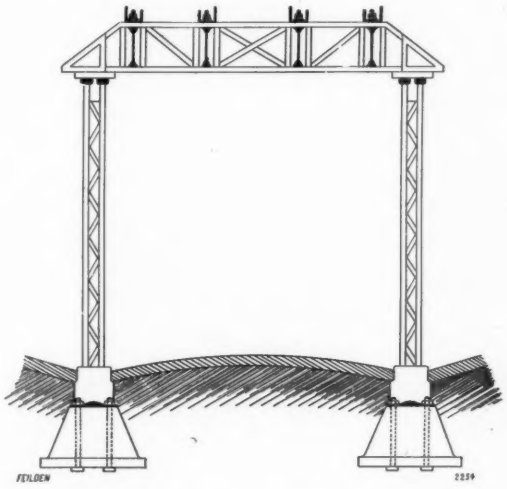
In connection with the Great Western Railway some mention must be made of the old timber viaducts adopted in Cornwall for crossing deep valleys which could not be filled up by embankments, except at great expense. In an interesting communication made recently to the Institution of Mechanical Engineers,* Mr. T. H. Gibbons describes these in

* "Railway Viaducts in Cornwall, old and new.", *Transactions* Inst. Mech. Engrs., July, 1899, p. 355.

detail. Those used principally in carrying the line across tidal creeks with deep muddy bottoms depended upon timber trusses to carry the decking and the railway, the trusses being supported generally on timber piles which formed the piers. The average span for this class was 40 ft., with height varying from 40 ft. to 100 ft. In cases, however, where better foundations were possible, masonry piers from 60 ft. to 66 ft. apart, and carried to within 35 ft. of the rail level were adopted, those of the more lofty viaducts being strengthened by buttresses. Twelve struts, kept in position and strengthened by walings and diagonal braces, radiated from the top of each pier, the top of the struts supporting the main carrying three beams which were doubled and joined together by raking bolts, joggles and keys. These viaducts have now all been reconstructed or replaced either by steel girders on the old piers, arched viaducts in granite masonry, or by erecting new, and enlarging the old piers to carry a wrought-iron superstructure.

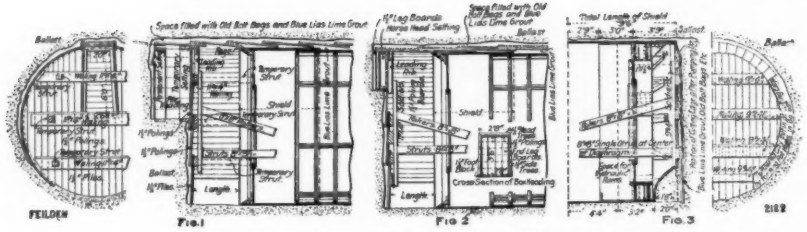
Cast-iron as a material for the construction of bridges was first used in railway work by the Stephensons. Brunel, however, did not make much use of it for this purpose, his objection to it reposing on the fact that repairs necessitated to such structures as a result of frosty weather or other causes were generally excessive. He introduced it, however, in cases where headway was very limited in the form of troughing let into the crown of brick arches. His objections were also probably founded on the fact that at that time sound castings of any large dimensions were not always possible to obtain. Wrought-iron, in spite of its cost, was a material Brunel employed in the larger of his bridges, as examples of which may be cited that carrying the Windsor branch of the Great Western Railway over the Thames, the Chepstow Bridge over the river Wye, and, finally, his last and culminating work, the Royal Albert Bridge over the river Tamar at Saltash. The structure at Windsor is a fine bridge on the bow and string girder principle. It has a span of 202 ft., and a truss of 23 ft. in height. It crosses the river in an oblique direction, and a system of diagonal bracing connects the whole of the top of the trusses to strengthen the arched ribs.

The greatest engineering achievement of Brunel is the Royal Albert Bridge. This is 2,200 ft. in length and 190 ft. high, and crosses the river in two spans of 455 ft. each, and on 17 side spans of minor dimensions. The piers are of masonry, that in the centre, on which are cast-iron columns supporting the main girders, being 35 ft. in diameter.



NEW YORK OVERHEAD RAILWAY.—DETAILS OF COLUMNS AND SUPERSTRUCTURE.

Each main span is arched in form, its chief members consisting of a wrought-iron oval tube, 16 ft. 9 ins. broad and 12 ft. 3 ins. in height, and two suspension chains falling from the extremities of the tube to a distance corresponding to the rise of the arched tube. The maximum distance between the tube and chains is 56 ft. Upright standards, connected by



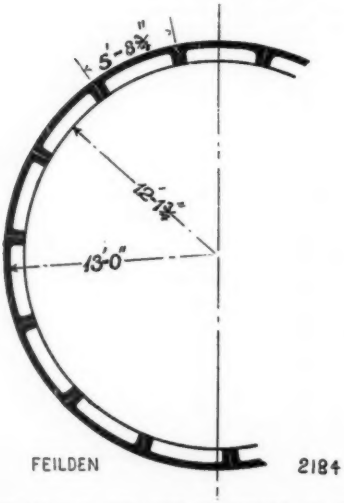
METHODS OF TUNNELLING WITH SHIELDS IN WATER-BEARING STRATA ON THE WATERLOO AND CITY RAILWAY.

diagonal bracing, are interposed between tube and chains at 11 points in each truss, the girders carrying the road being suspended from each of these at intermediate points. The total weight of ironwork in each span is 1,060 tons, and the cost of the completed structure was £225,000.

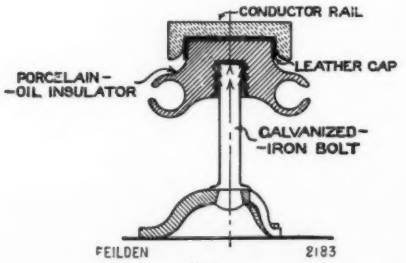
Advantage may be taken here of contrasting with the above bridge the masterpiece of Robert Stephenson, viz., that carrying the railway over the river Tyne at Newcastle, the last link which was to connect, by the East Coast route, the English and Scotch capitals.

The bridge, which is a true example of a bowstring arch without cross-bracing, has six spans, each of 125 ft., which, as in the case of the Saltash bridge, combine both the arch and suspension principles. The cast-iron arched ribs, four to each span, are arranged in pairs, the inner pair 2 ft. 4 ins. apart, a space of 6 ft. 2 ins., utilised to form a footpath, separating each outer pair. The tops of the arches support the girders carrying the railway, and wrought-iron vertical tie rods join up this to a lower flooring, which constitutes the carriage roadway and footpath passing under the railway. 4,728 tons of cast-iron and 321 tons of wrought-iron were used, and the whole cost of the structure amounted to £243,000.

Another well-known structure contemporary with the above, and by the same engineer, is interesting, from the fact that it was more or less experimental; its costly nature and high wind resistance causing its example, except in two instances, not to be imitated. Both the Britannia and Newcastle bridges may be



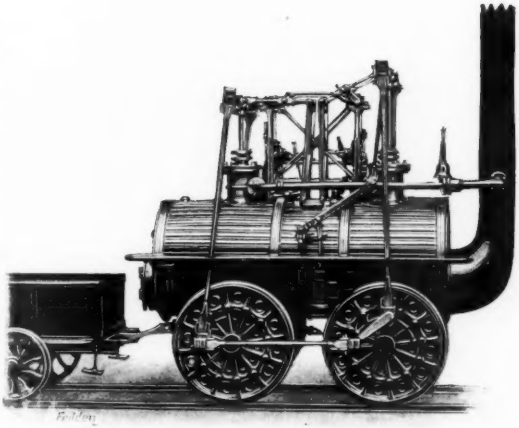
WATERLOO AND CITY RAILWAY.—DETAILS OF IRON TUNNEL LINING.



WATERLOO AND CITY RAILWAY.—CONDUCTOR RAIL AND SUPPORT.

said to represent an intermediate stage of bridge construction, the latter being the middle term between the arch and the beam, the former transition from the plate girder to the open girder type.

In the Britannia bridge the plate girder is enlarged to form a tubular beam 15 ft. wide, and with a varying depth of from 25 to 30 ft., the rails being laid along the bottom, one line of way in each tube. The supports consist of two abutments and three masonry piers, the central structure rising to a height of 230 ft. The bridge is split up into four spans, the maximum being 460 ft., the smaller 242 ft., and the tubular beams were constructed to these lengths on shore, floated out on pontoons, and raised by hydraulic presses. Each section was united through the piers by shorter lengths being built in. The total cost of the structure was £601,865, which is equivalent to £398 per foot run.



THE "LOCOMOTION," THE FIRST ENGINE TO RUN ON A PUBLIC RAILWAY, VIZ., THE STOCKTON AND DARLINGTON.

In the Newark Dyke bridge, with a total length of 259 ft. and a clear span of 240 ft. 6 ins., on the Great Northern Railway, built in 1851-3, we have the earliest example of a Warren girder bridge; but space will not permit a detailed description.

The Forth bridge, so familiar as being the largest and most magnificent structure of its kind, is constructed on the cantilever principle, from designs by Sir John Fowler and Sir Benjamin Baker, Sir Thomas Bouch's design for a suspension bridge across the Forth having been abandoned in consequence of the apprehensions awakened after the collapse of the Tay Bridge.

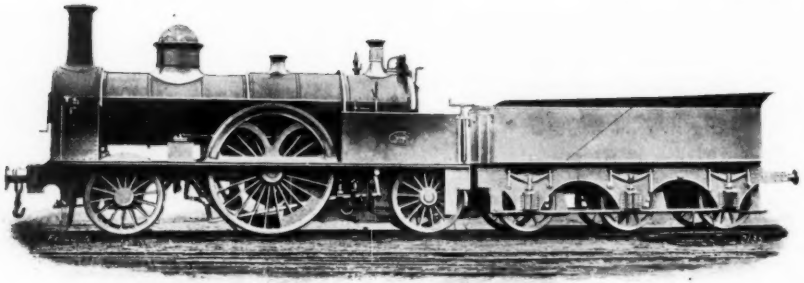
The structure consists of two main spans, each of 1,710 ft., with a central pier on the rock of Inchgarvie. There are also two other spans of 675 feet each at the shoreward ends of the cantilever, fifteen of 168 and twenty-five of minor dimensions.

The main piers are of masonry and concrete, with foundations in rock or boulder clay, the deepest being 70 ft. below water level, with diameters of 53 ft. at bottom and 49 ft. at the top.

The maximum distance from the high-water level to the top of the superstructure is 361 ft. and a clear headway is given of 150 ft.

The cantilevers, constructed of the best Siemens steel, are on the double lattice-work system, and connected with one another by ordinary girders. The columns over the piers are 12 ft. in diameter and 120 ft. apart at the base and 33 ft. at the top, and to carry out this principle of offering an effective wind resistance, the cantilever bottom members widen out at the piers. All the main members in compression are tubes, while those in tension are of the lattice type, the stability of the whole structure being further increased by the addition of lattice girder wind bracing.

To form some adequate idea of the vastness of the work it may be stated that the weight of steel in the main spans is 51,000 tons, and that 21,000 tons of cement, 47,000 tons of granite, and 113,000 tons of stone were used in the construction. The total cost, including that of the new railways necessary to form



ONE OF MCCONNELL'S "BLOOMERS," A POWERFUL CLASS OF LOCOMOTIVE IN USE ON THE LONDON AND NORTH-WESTERN RAILWAY IN THE FIFTIES.

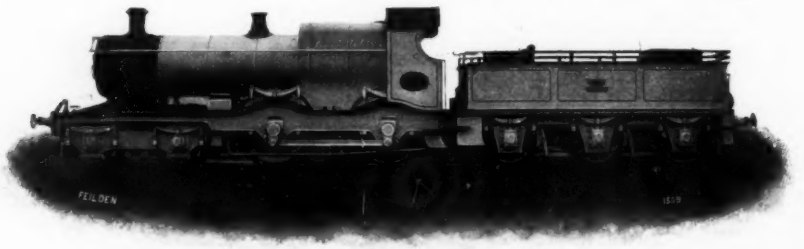
Diameter of cylinders 16 ins., stroke 22 ins., weight 28¾ tons, heating surface 1,152 sq. ft., diameter of driving wheels, 7 ft.

the connections with the North British Railway system, was £3,367,600.

The fact that this bridge, or indeed railway engineering at all as it is to-day, was rendered possible is owing to the introduction of cheap steel. In the form of steel rails it has lessened the prime cost and increased the durability of the permanent way, and permitted speeds and train-weights which with the use of iron rails would have been altogether impossible.

Space will not permit the tracing of the development of the rail from its primitive form to the type at present in common use, but a diagram on page 167 clearly sets out the essential details of the pattern and weight of those employed on the Great Western Railway since the opening of the line.

A brief reference must here be made to the Metropolitan and Metropolitan District Railways that run generally underground in and about London, an enterprise which perhaps did as much to establish the reputation of the late Sir John Fowler as the Forth Bridge itself. This progenitor of the underground systems of metropolitan transit was opened for a portion of its length in 1863, although the Inner Circle was not finally completed until twenty years later. The railway is, for the most part, in covered way, although tunnels proper and open cuttings with retaining walls occur in places. In the older portion of the line, designed to accommodate broad-gauge traffic, the covered way takes the form of an elliptical arch having a span of 28 ft. 6 ins., and with a rise of 11 ft. The arch proper, which is laid with six



A MODERN TYPE OF EXPRESS LOCOMOTIVE, ONE OF THE "BULLDOG" CLASS USED ON THE GREAT WESTERN RAILWAY FOR WORKING THE SEVERE SOUTHERN SECTIONS OF THE LINE.

Diameter of cylinders 18 ins , stroke 26 ins., heating surface 1,663 sq. ft., diameter of coupled wheels 5 ft. 8 ins.

rings, is supported by side walls 3 bricks thick and 5½ ft. high from rail level to the springing of the arch.

In lengths of a more recent date the width was reduced to 25 ft. and the height to 15 ft. 9 ins. In all cases the footing courses are in concrete, and the haunches of the arch are backed with the same substance.

Inverts have been added between the footings where additional resistance to lateral pressure or other reasons rendered this advisable.

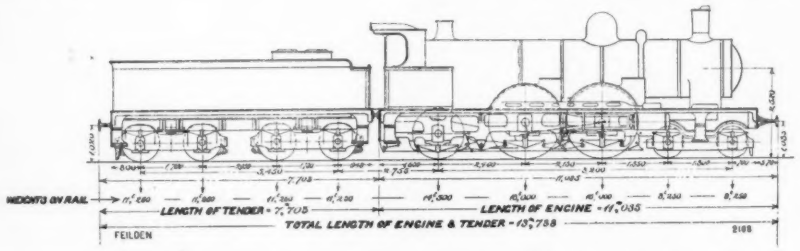
Cast-iron girders with jack arches have been adopted where there was not sufficient depth for brickwork, and side walls in this case being constructed of brick and concrete in bays.

after which the arch was turned and the dumpling removed to the formation level.

The same plan was adopted in the construction of the open cuttings, which on the earlier lengths are 28½ ft. wide and 25 ft. in those of a later date. The retaining walls of brick and concrete are built in bays and have a batter of 1 in 8, with foundations 5 ft. below the rail level.

The subject of effective ventilation while the use of steam locomotives has been the method of traction, is one that has continuously been a source of trouble to the company and discomfort to the passengers.

It is not, therefore, a matter of surprise that the companies concerned are taking steps to apply remedial measures by the



LATEST TYPE OF FOUR-CYLINDER COMPOUND EXPRESS LOCOMOTIVE, CHEMIN DE FER DU NORD, ONE OF WHICH WAS EXHIBITED IN THE PARIS EXHIBITION, WHILE ANOTHER MADE RECORD PERFORMANCES BETWEEN PARIS AND CALAIS.

The tunnels proper on the line are three in number, viz., the Clerkenwell, 728 yards long, one 733 yards in length constructed subsequently and running parallel to the first, and the tunnel under Campden Hill, 421 yards.

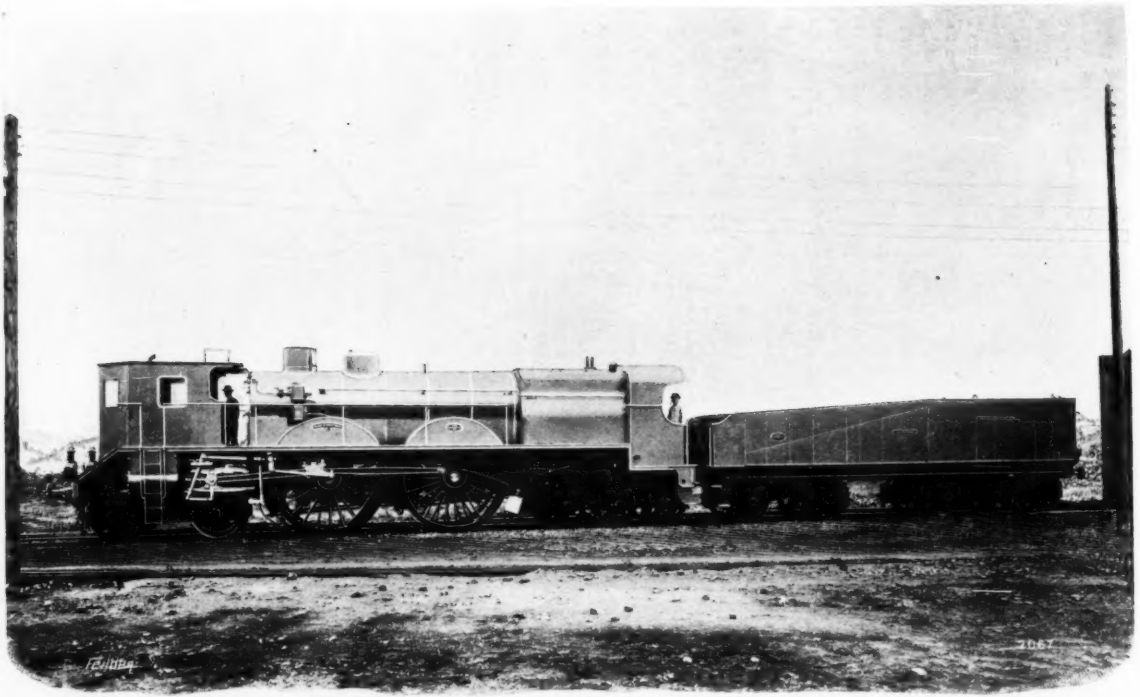
From the circumstance of having to drive under a town many difficulties occurred, and it was only by working in very short lengths that risks were minimised.

The method of working was at first by means of an open cut, in which timbering for the whole width was resorted to. Later, however, two 6-ft. trenches were excavated to receive the side walls, then the timbering was removed, and replaced by concrete filling as the work proceeded. The dumpling was then cut down to a depth sufficient to admit the centering,

substitution of electric traction. This is a measure which is both interesting and significant in that it may foreshadow what after all may happen in the course of time on many of our trunk lines in this country, namely, the supersession of the steam locomotive by electricity.

In February, 1899, the associated companies voted £20,000 for the electrical equipment of 5,000 ft. of line between Earl's Court and High Street, Kensington, on the insulated return system.

The electrical conductors, of inverted channel steel, weigh 75 lbs. per yard, and are carried on double insulators, the jar being taken by a piece of leather. The bonding is by copper strip hydraulically riveted. There are two positive and two negative feeders, lead-covered and armoured. The power house contains



FOUR-WHEELS-COUPLED DOUBLE BOGIE COMPOUND EXPRESS LOCOMOTIVE, SYSTEM THUILE.

This engine, constructed for the Société d'Étude des Trains Internationaux by MM. Schneider et Cie., is really an experiment. It probably represents the ultimate dimensional and power limits to which the four-cylinder compound system will attain under the present rail and loading gauge.

engines of 300 i.h.p. at 380 r.p.m., and the dynamos give 385 ampères at 550 volts.

There is only one train, and it requires current for about three minutes in every twenty; it has a motor car at each end, but only one is used at a time. In the event of this type of train being adopted on the Inner Circle it would of course only want one motor car, because the trains always move in the same direction. Each motor carriage has four four-pole 26 × 25 Siemens motors, series wound, with armatures built on the axles. Each motor develops a normal draw-bar pull of 4,000 lbs., the wheels being 47 ins. diameter, and the maximum power about 200 h.p.

Current is collected from the conductors by 14 (seven on each side) cast-iron shoes suspended from the bogies by insulated bolts. When fully loaded the train has started on a 1 in 43 gradient—a feat which an ordinary steam locomotive was unable to perform when hauling a similar load. Maximum speeds of 38 to 39 miles an hour have been reached.

This experiment, adopted as it has been in order that the companies might accumulate experience of their own without depending wholly on that of other railways, has apparently proved satisfactory, as quite recently they decided to electrically equip the whole of the system, and have to that end invited tenders and schemes from the leading electrical firms to be submitted.

It is confidently expected that the introduction of electric traction on these lines will give an increase of speed, the acceleration arising from the greater speed with which the electric train gets away.

The idea of utilising electric power for propulsion is not new. In 1842 an electro-magnetic locomotive, weighing five tons and running on four wheels, was tried on the Edinburgh and Glasgow Railway, when it attained a speed of four miles per hour.

In 1881 electric power was applied to a line near Amsterdam 1½ miles in length, to a mine railway on the Continent, and to a line at the International Electric Exhibition held at Paris in that year. In 1883 a line six miles in length, of 3 ft. gauge, using electric means of propulsion, was opened between Portrush and Bushmills in Ireland. The gradients on this line are heavy, rising to as much as 1 in 35 at given parts; the curves are also frequent and sharp, the permanent way following the line of the road. Steel brushes transmit the current to the motors from the conductor, which consists of a third rail weighing 19 lbs. to the yard.

In December, 1890, the City and South London Electric Railway was opened. This was the first example in the Metropolis of an underground railway system in which electricity was used as a motive-power. The success and popularity achieved by this line caused its example to be followed in the Waterloo and City electric line, opened a year or two later. Space will just permit a brief notice of this line, which will serve as a representative of what promises to be a widely-adopted system in the Metropolis, as to-day the Central London Railway is in full work, and several other lines are either in actual course of construction or powers have been obtained.

The Waterloo and City Railway commences on the southern side of the London and South Western Railway, penetrates the bed of the River Thames 165 yards above Blackfriars Bridge in a diagonal direction, the tunnel tops being 23 ft. below the bed, and finally terminates a length of 1 mile 46 chains at a point near Cheapside. The rail level of the tunnel at the Waterloo end of the line is 41 ft. below the level of the London and South-Western Railway, while at the City end it is 59 ft. below the surface. The tunnel, which is of cast-iron, has a minimum internal diameter on the straight and in flat curves of 12 ft. 1¾ ins. between the flanges.

The cast-iron lining consists of a series of rings, each 20 ins. long, each ring being made up of seven segments, with a key-piece at the top. Creosoted yellow deal packings are placed between the successive rings, the segments of which are joined to one another by 1-in. bolts running through slotted holes in the joints. The longitudinal joint of each segment has three 1-in. bolts through it, and there are eight such joints in each ring.

When the material consisted of clay the Greathead shield was used exclusively in

the tunnelling operations, the diameter of the shield being 2 ins. larger than that of the cast-iron lining.

The trains are worked by electrical energy supplied from the power stations at the Waterloo end of the line, the current being carried by insulated cables to a main switchboard, from which a separate cable conveys it to each of the two tunnels, there being one line of way in each tunnel. The cable forms the feeder, the current being tapped at several points along its length by branch cables laid under the running rails of the permanent way. A central conductor runs between these rails at a height level with their surface, and four collector shoes on each train slide along the surface of the conductor rail, and make contact with it. The current so collected is carried to the two drivers' cabs at each end of the train, and is returned to the power-house by the running rails, which are bonded and connected in parallel. Each train consists of four bogie carriages, and an electric motor is fitted to each axle of the bogies at the ends of the train.

The permanent way is of the London and South-Western Railway pattern, consisting of bull-headed rails weighing 87 lbs. to the yard and carried on longitudinal sleepers.

The tendency in the construction of Metropolitan electric railways is towards deep-level lines, as the constructional difficulties attaching to the cut-and-cover system, such as were encountered in the making of the Metropolitan, District, and Paris underground railways, and the consequent blockade of traffic, are sufficient to prevent the employment of the method which brings the station platforms as near the surface as possible, thus rendering access more easy and expeditious.

The overhead method, first adopted in New York in 1872, has been carried out with great success in Liverpool in a line the first portion of which was opened in 1893 and an extension three years later.

It traverses the Liverpool Docks for a length of about 6½ miles on the eastern shore of the River Mersey, and in its essentials consists of plate girders supported by columns placed vertically about 22 ft. apart, giving sufficient width above for two lines of way of standard gauge, and below for two lines of dock railway. The columns supporting the superstructure consist of two steel channel bars riveted to two steel plates, thus forming a box-column. Plate girders were used for spans up to 75 ft., while bowstring lattice girders were used for the 98-ft. spans.

The plate girders carry a parapet which forms a continuous footway on each side of the line.

Hobson's patent flooring is used, upon which are laid and keyed longitudinal sleepers. The permanent way consists of flat-bottomed steel rails, weighing 56 lbs. per yard, while a steel bar of 4-in. section, carried on porcelain insulators and placed midway between the rails, forms the conductor.

Cables laid underground connect the conductors and rails with the generating station, the return current being brought back through the rails.

Whether high or deep level, or at a slight depth below the surface, the construction of Metropolitan railways has always followed, and probably always will follow, certain well-known and well-tried types, the main forms of which will probably be found in the Central London, the Paris Metropolitan, and the Liverpool Overhead railways.

As far as the steam locomotive as a tractive force is concerned, it would appear that British locomotive engineers in their present practice have reached the limit of power economy and power sources that are available with the existing rail and loading gauges, any further development being possible only in the direction of compounding. This system has been rapidly developed in France in the hands of MM. de Glehn and du Bousquet, with results that can only be characterised as remarkable, both as regards speed, economical steaming, and in the ability of the engines to take a heavy load up a gradient with a constant acceleration.

We may perhaps expect to see British locomotive development taking place along the same lines, although at the present moment British railway managers and locomotive engineers regard with apparent

indifference the good results obtained by a system which has been universally adopted on French main lines.

That electricity as a motive-power has proved its suitability in Metropolitan railway systems is now certain, and the continuous demand being made for higher speeds and more luxurious trains on trunk lines can only be settled, without the expense of providing a heavier permanent way or reconstructing many of the works, by adopting the same energy.

For probably the first time the crux of the question, which consists in whether electricity can economically compete with steam in the haulage of a paying load for a given distance at less average cost and at the same or accelerated speeds, was submitted quite recently for professional consideration by Mr. W. Langdon, in a paper read before the Institution of Electrical Engineers.

From data brought forward, and experiences related both by the author in his paper and in the after criticisms, it would now appear certain that the adoption of electricity as a motive-power on trunk lines would mean a reduced expense per mile, not perhaps immediately due to any one large item—as, for instance, an economy in coal consumption—but to the many minor expenses which would no longer be necessitated.

The stimulus which the reading and discussion of Mr. Langdon's paper must give to further investigation and trial in this direction may justify the presumption that the period is not distantly remote when the electric system of haulage will be adopted on some trunk line. Meantime, the conversion of the Metropolitan and District Railways will be watched with considerable interest.

C. L. Allen

The Unity of the British Empire and Imperial Telegraphic Inter-Communication.

By F. G. McCUTCHEON.

MR. F. G. McCUTCHEON has, at one time or another, edited and issued various publications dealing with subjects of an advanced and progressive type, and at present finds time to eitd an old-established monthly trade journal.

For fifteen years he has been specially interested in the subject of telegraphic communication. His first book, "The Telegram Formula," he published in 1885. Since that period he has compiled and issued many other codes, but his reputation is chiefly associated with the name of Mr. C. Algernon Moreing in the production of the "Moreing and McCutcheon's General Commercial and Mining Telegram Code," a volume of some 2,500 pages, constructed upon a scientific method greatly in advance of other productions of the same nature. This volume is to be followed shortly by other works by the same authors, which will mark still further progress in the development of this most important adjunct of modern business requirements, namely, the art of telegraphic cypher correspondence.

THE problem of Imperial unity which is now occupying the minds of so many of the leading statesmen in this country as well as in the Colonies has been declared to depend for its solution upon a variety of bases. There are advocates for the establishment of an Imperial Assembly or House of Representatives from every portion of the British Empire who attach supreme importance to this particular feature of the question. Others consider that in the establishment of a Customs' Union for the purpose of directing and confining within the limits of the Empire the bulk of the trade of the various sections, for the mutual benefit of the Imperial population, is to be found the most powerful bond for ensuring their permanent unity. Amongst other important factors are the consolidation of the military forces of the various sections for the general defence of the Empire, the gradual further increase and improvement of transport and postal

communication, and, finally, that which is probably the very foremost and most essential factor of all for the purpose of maintaining not only the nominal political and commercial unity of the British Empire, but that vital power of central control without which no true unity can permanently exist, viz., a complete system of Imperial Telegraphic Inter-Communication.

As in the first instance the perception of the great advantage to the British mercantile community of more rapid communication with its various centres in distant parts of the world contributed to the successful reception of submarine telegraphy, so the increased necessities of British commerce have led to the extension of the telegraphic service by the laying of various cables to connect all our most important commercial centres. The volume of correspondence daily necessitated for the transaction of business in distant countries continues to increase from year to year, and a profitable return for the money invested is being realised by the various cable companies. These comparatively new channels of communication, which have been silently playing so important a part in the development of the commercial, social, and political relations of the principal nations of the world and in the unity of the British Empire, are about to enter upon a greater and even more important sphere of usefulness than that which has hitherto been recognised as their peculiar function. These throbbing arteries of the visible universe will in time to come be more generally utilised for conveying to the various nationalities not only the bids, bargains, and contracts in the world's produce and manufactures, but the every-day social intercourse and friendly sentiment, which will, it is hoped, gradually extend itself, and serve to create ties of stronger interest and better feeling than those which have hitherto manifested themselves as influencing the conduct of the nations of the world with respect to their relations and intercourse with each other. It is necessary that these leaders of thought should be utilised to the utmost for the education of the nations.

The possession of the earliest and most accurate information constitutes the chief source of power. It is imperative upon British merchants and manufacturers to fully utilise the telegraph cables if they would maintain their commercial supremacy, not only for correspondence respecting the produce of distant countries, but also for that relating to the manufactured articles which they export from Great Britain. The intending purchaser abroad of any manufactured article, immediately he has determined to make a purchase, is desirous of losing no time in obtaining the article required, and he will be most disposed to send his order to the country where it will be executed and the article delivered to him in the shortest time. The manufacturers who afford their probable customers in distant parts of the world the opportunity of communicating with them by cable respecting their goods are likely to attract the largest amount of trade, as the element of time in the execution and delivery of any order is a very important one to the purchaser. If American or German manufacturers afford greater facilities than British manufacturers to buyers in distant parts of the world for the execution and delivery of any order, the orders will be sent to the former in preference to British manufacturers.

It may be asserted that such orders by telegram could not conveniently be executed in such a direct manner, and that the volume of trade must flow through the banking and shipping firms, who generally act as intermediaries. Conditions of trade which were suitable to a past era must, however, be reorganised to suit the new circumstances which have arisen. If the British shipping and banking facilities for the execution of orders from distant parts of the world are not the most expeditious which modern exigencies demand, it is probable that the manufacturers of rival countries will succeed in organising something better, which may attract a considerable portion of the world's custom from the British merchants and manufacturers. British merchants and manufacturers, therefore, must leave no stone unturned to see that they have the very

best organisation for firmly maintaining the threads of communication with all likely customers in all parts of the world. Looking back to the past, in the development of the commercial progress of Great Britain the important influences can be discerned at successive stages, which have been effected, first, by the improved means of internal transport, such as that of roads, canals, and railways; then again by improved postal communication; then again by a more enlightened and extended source of information, disseminated by means of our newspapers and trade journals; and, lastly, we are now witnessing the development of that most wonderful stage of progress inaugurated some years since by the introduction of improved steam vessels and telegraphy, and the gradual extension of steamship lines of communication and telegraph cables to all parts of the world.

Hitherto the British community has enjoyed somewhat of a monopoly of the cable traffic.

In laying cables for our own needs we have at the same time afforded other nations the convenience of using them. They can communicate with our customers in all parts of the world, and possibly ship their goods by our vessels. We have therefore to a great extent invited competition.

There are unmistakable signs that other countries are awakening to the fact that it is not desirable, from their point of view, that the British should be the monopolists of the world's intelligence.

The Americans, the Russians, the French, and the Germans have all extensive schemes for laying telegraph cables and land wires.

We have given them an ocular demonstration of the advantages of possessing the control of these vehicles of communication. They are not slow to perceive that the British commercial traffic from any important point might easily be diverted by a cheap tariff, and in order to gain such traffic their governments would, no doubt, be prepared to grant heavy subsidies to telegraph cable companies to enable them to compete with British routes.

The purely commercial mind would probably consider that it was of little importance whether a Russian company took the British merchants' message at 2*s.* per word and the British Cable Company was compelled to compete against it at a loss, or whether the Russian Cable Company took all the traffic, provided the British merchant succeeded in getting the lowest possible rate.

The question, however, has another very important aspect besides the purely commercial one.

The Imperial Government requires the cables and land wires for the instruction of its diplomatic officials and for the perfection of its executive organisation in every portion of the Empire, and the more perfectly this system of inter-communication is organised the stronger will be the welding of the integral parts of the Empire.

No other Power can be permitted to act in the capacity of intermediary messenger or transmitter of the Imperial word.

As it needs no great foresight to perceive that telegraphic cables and land telegraphic wires are a necessity to the Imperial Government, why need the question as to their most complete utilisation be any longer shirked and shelved and allowed to drift whilst other nations are straining their utmost to get ahead of us in this respect, and to divert the telegraphic traffic which brings us such a large percentage of the commercial business of the world, and benefits not only the commercial community, but the population generally of the whole British Empire?

The volume of telegraphic cable correspondence may be classified under the following three important divisions:—

1.—*The Commercial Correspondence:* that is, correspondence which arises solely from the exigencies of commercial transactions.

2.—*The Imperial Government Correspondence:*

(a) The Diplomatic correspondence connected with the secret international relations of the State.

(b) Correspondence necessary for

the conduct of the Departmental business of the Imperial Government.

(c) Correspondence concerning Imperial subjects of general public interest which should be collected and published by the Imperial Government.

3.—*The non-Commercial Correspondence*, which consists of communications relating to social and semi-educational affairs.

Amongst the many questions which will have to be considered consequent on the general desire manifested by the Colonies to be more closely associated together with the United Kingdom as members of one grand Empire, the Imperial Government, however that may be constituted in the future, must be provided with a properly organised system of cable correspondence and cable intelligence for the use and information of the various sections constituting the Imperial Union.

As in the past, it has been necessary for the Government of the United Kingdom to organise, subsidise, and develop our important Postal Service, so now it is necessary that the organisation, assistance, and development of this improved and more rapid means of communication should be undertaken, so that every possible facility for inter-communication is afforded between all the important points of the Empire. The means of inter-communication need increasing by the laying of additional cables. The rates charged for messages require to be reduced to the minimum. Information concerning certain Imperial subjects of general public interest should be collected and transmitted by telegram for immediate publication, so that the subjects of the Empire can look with confidence for correct intelligence from official sources to allay disquiet caused by unofficial reports, more especially in times of sudden emergencies.

The organisation and distribution of this class of telegraphic news should be undertaken by the Government for the purpose of educating the general public with reference to matters of interest occurring in the various parts of the Empire which may be regarded as of a semi-educational character and of a general nature connected with agriculture, trade, navigation, finance, mining, general statistics, etc.

It is necessary that there should be an end to the want of system of public news, which for years past has left the country in dependence upon two or three private organisations which, more by good luck than otherwise, have not very greatly misled or wilfully abused the confidence which has been placed in them by permitting them to become the sole channels of information to the British public with reference to events in different parts of the world where British officials might have been utilised for sending the public intelligence.

Commercial agencies are established for the sole purpose of making a profit, and whether it be offered by a Boer, Russian, French, or German Government, the incentive of a handsome fee to transmit certain information which will influence and direct the public mind is a temptation perhaps too strong for some such agencies, more especially as all comers are permitted to engage in such undertakings, and it would be quite possible to establish in London such an agency, supported by foreign government funds, to supply our newspapers with biassed information, to say the least, and at the same time secure the favours so freely granted to the Press organisations of early and sometimes confidential news.

Hitherto the advantage of a good telegraphic cable system has been mainly extolled in its capacity as an aid to the extension of commercial relations. The increase of commercial interests, it has been argued, would bring about an increase of correspondence, and the increase of correspondence will knit us closer to our Colonies and Dependencies. It has been assumed that such must be the direct result without the necessity of any effort being made to counteract any possible opposite tendency, and it has been maintained that there are no other interests so important in influencing the union of our Colonies as the commercial interests. It is now recognised, however, that we can

no longer afford to ignore or neglect the vast Imperial interests other than those exclusively commercial which are vitally connected with the functions of what has been designated as the nervous system of the globe. These functions comprise a conveyance of communications other than those solely relating to commercial intercourse. The cable system must be utilised to its fullest extent as a vehicle for the rapid transmission of thought, for the benefit, as far as possible, of all sections of the communities embraced within the British Empire as well as the purely commercial section. Royal messages, Government despatches, naval or military commands, legal verdicts, and commercial contracts can all be almost instantaneously transmitted to all parts of the British Empire. The older and more circumscribed vehicles for the distribution of thought as represented by our journals and magazines, though supplemented by this still greater vehicle for the receipt and dissemination of world-wide intelligence, may at no distant date find themselves altogether forestalled and preceded by a system of intelligence which is distributed to the individual without the time and trouble expended in the previous preparation of a printed sheet. With a well-organised Inland Telephone system important cable news from distant parts of the Empire could be more rapidly distributed than by the agency of the printed newspaper. In the United States of America a combination has been formed for the purpose of working the telephone system in connection with the Cable Companies.

As the Newspaper Press of a country has in later years been considered as a standard by which a judgment can be formed as to the commercial and general education of its people as compared with other nations of the world, so also will the telegraphic intelligence of any nation form a criterion of its power and influence in all quarters of the globe. Fortunately for Great Britain, London and the principal cities of the United Kingdom have hitherto maintained for this country its supremacy as a telegraphic news centre, the importance of which it is difficult to over-estimate. So accustomed are we to regarding this country as the first receiver of telegraphic news from distant parts of the world, that few pause to consider what might be the case if this favourable position should ever cease to be maintained. Our supremacy in this respect has arisen through our commercial, financial, and political importance in the world, which led us to initiate a telegraphic cable system to our Colonies and Dependencies. Beyond using these cables for our commercial correspondence, but little has been done to utilise these vehicles of communication by organising and developing an intercourse between the several nationalities which have been brought into such closer means of communication by these connecting links. If the telegraphic cable is a vehicle of thought by means of which it is possible to influence the people to whom we are allied, politically and socially, as well as commercially, as members of a great Empire the unity of which it is essential to cement and maintain, why should not the telegraphic cables be utilised for an organised system of correspondence in various grades of thought as well as in the commercial sphere. It is not a great many years since our newspapers, trade journals, and magazines were comparatively few. The lines of thought upon which they appealed to and interested their readers were presumed by many to cover all possible channels. Yet year by year they continued to increase, and as new sources of knowledge developed and new veins of thought were tapped, so each existing newspaper and journal developed fresh subjects, and altogether new journals of a quite different class were added to our list, until the number of newspapers, journals, and magazines at the present time is treble what it was but comparatively a few years since. So, also, in the case of our telegraphic intelligence relating to distant parts of the Empire, subjects with reference to which a few years since the newspapers obtained no information whatever, now regularly appear in their columns, and these are destined to increase in number and diversity from year to year, though the development will

necessarily be slow unless efforts are made to direct, stimulate, and educate the interest of the Imperial public.

We have recently had a striking demonstration of the fact that commercial interests are not the only ones that bind the people of the various sections of the British Empire. No special thoughts as to increased business and larger profits could have entered into the minds of those who willingly abandoned their homes and belongings to shed their blood for the sake of maintaining the supremacy of the British Empire. In the train of these are thousands of others looking for some sympathetic chord or bond of union to draw them still closer, that they may realise their membership of the Empire. It may be termed a mere sentiment or idea only, but it is strong within the individual, and these sentiments and ideas require a corresponding sympathy to flow out from the centre which will gratify, attract, and bind together the various communities comprising the whole of the British Empire.

Though our commercial interests have been presumed to be the great bond of union between the United Kingdom and its various Colonies and Dependencies, the presumption only holds good so long as the inter-trading proves profitable. It is obvious that international trading cannot be conducted altogether upon feelings of patriotism, as to be successful we must endeavour to buy in the cheapest market and sell in the dearest wherever this object can most satisfactorily be attained. If this be a truth, what grounds have we for assuming that the commercial interests and inducements of the various members of the Empire will always prove sufficiently profitable for them to confine the greater part of their extensive trade within the circle of the various communities constituting it? It is obvious that we have no just grounds for any such assumption. It is possible that the bulk of the present trade with our Colonies and Dependencies might be diverted from the people of the United Kingdom, in which event, if it be true that the commercial interests of the various sections of the Empire are the principal factors which consolidate its union, then the converse must be equally true that the absence of these commercial interests must involve a disruption and disunion of the Empire. Therefore, to rely solely on the commercial interests existing between the various sections of the British Empire as being the bond of unity cementing the same, is to rely upon an uncertain and fluctuating factor which, though admittedly exercising a great influence at certain periods, as at the present, cannot be absolutely relied on as a permanent and enduring influence. It is evident therefore that the commercial interests are not such important factors in the maintenance of the unity of the British Empire as many have assumed. There must be other influences stronger and more important even than the purely commercial interests.

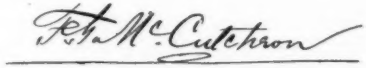
Great as the commercial interests of the United Kingdom are with the Colonies and Dependencies of the British Empire, as well as with foreign countries, and voluminous as the telegraphic correspondence which relates solely to commercial transactions has become with these distant parts, it is surprising that the commercial community has organised no mutual association for the collection and distribution of news which is of Imperial commercial importance from the distant districts with which they trade. The telegraphic cable correspondence relating to purely commercial interests would be far more efficiently conducted by an association of commercial men who would utilise their correspondents in distant parts who are thoroughly conversant with all the circumstances which affect the conduct of the trade or industry in which they are specially interested than by a self-constituted news agency or Government Department. No Government Department could conduct this portion of the correspondence so efficiently as an Association of Merchants and Manufacturers. An association of this description could not only be organised for the purpose of keeping merchants and manufacturers informed as to all important events of general commercial interest in distant parts, but a great economy could be effected in the transmission of the bulk of the correspondence by the use of an efficient

code service, which would enable them to effect a considerable saving upon the ordinary rates charged for cable messages, and which, whilst relieving the sender of a message of a needless expense, also relieves the cables of a superfluous volume of traffic by reducing the words to be transmitted to a minimum. It is clear that anything which contributes to enable a cable, the laying of which has entailed a large expenditure of capital, to perform a considerable proportion of its total work at a saving, say, of from 25 to 50 per cent., must prove to be an important factor towards showing a profitable return on the capital expended.

The cable companies have not hitherto made any extensive use of code systems for the economising of words in the transmission of their own messages, yet it seems certain that the principle must play an important part in the future, when the reduction in the volume of traffic on the cables will become of even greater importance to the companies themselves than it is at the present time. Assume, for instance, the existence of a cable line with a congested traffic, able to earn a satisfactory dividend, yet the probability of the same company being compelled to lay an additional cable and increase its capital expenditure perhaps nearly double the amount, though the corresponding increase in the amount of traffic to compensate for this large outlay would be comparatively trifling for some years to come. There might be sufficient traffic to pay a fair dividend for the capital expenditure on one cable, but not sufficient for many years to pay for the total capital expended on both lines of cable. Though the public are permitted to send cable messages in code, by which within certain limits a considerable saving can be effected over the ordinary rates charged by the companies, yet the cost and trouble to individuals of compiling a good code system prevents many from fully availing themselves of this advantage. By the establishment of an organisation of Merchants and Manufacturers for economising messages the principle could be extensively applied for the general benefit of all belonging to the Association.

Sir Edward Sassoon has done considerable service to the commercial world in calling attention to the difficulties under which the cable correspondence is at present conducted, and, as the representative of the Imperial Telegraph Committee of the House of Commons, specially called the attention of the Government in February last to the necessity of giving a very full consideration to the whole subject of Imperial Telegraphic Communication, and obtained from the Government an assurance that the many important questions involved would be fully, though privately, inquired into at as early a date as possible.

In addition to the question as to the high rates for words charged by the cable companies, and the laying of additional cables, the questions which have been enumerated in this article as to the full utilisation of the cables for telegraphic correspondence may possibly prove worthy of consideration also.



Machinery in Fiction.

By ETHEL WHEELER.

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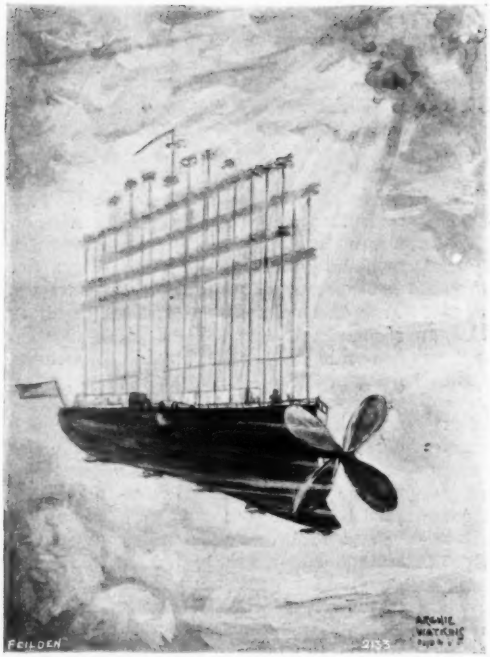
THE Future has always proved the most alluring of speculations to the mind of man. Supposing the Present to be represented by a certain sum of facts and figures: the problem is to find what answer the ages will work out in addition, subtraction, multiplication, and division.

This problem has been approached in various moods. Grave philosophers have set forth their solutions in such works as "The Republic" and "Utopia"; dreamers of beautiful dreams have evolved out of the ugly prose of the period the exquisite ideals that are embodied in "News from Nowhere" and "The Crystal Age." These lofty political treatises, these delicate imaginings stand for all time; but the present condition of things has given rise to a vast body of ephemeral speculation, of adroit sophistry, which, if it lives at all, will live, not because it is literature, but because it is curiously characteristic of a passing phase of thought. And because the invention and development of machinery constitute the most remarkable feature of this century, so it is chiefly with the future of machinery that many of our contemporary novelists concern themselves. Their works are not, as a rule, serious in intention; they are rather to be regarded as freaks of ingenuity, that link with an airy thread the Actual and the Impossible. At the same time it must be remembered that imagination has constantly anticipated the slow pace of science, and that many of the extraordinary inventions of fiction may at no distant date be translated into material form.

Sometimes these speculative writers push their machines merely over the threshold of fancy, and by a multitude of technical details insist that their mechanism is still within the boundary of fact. This is the method employed by Jules Verne. Others give their imagination freer fling, and seek to impart conviction, not so much by minute description of machinery as by accumulated argument and circumstance. This gives us the Time-Machine and Martian Fighting Machines of H. G. Wells.

Beside these two builders of definite machines that can to some extent be visualised, we have those writers who, by a bolder flight, endow mechanism with consciousness — a most heterogeneous class, including the author of "Erewhon," George Eliot, Bulwer Lytton, and Rudyard Kipling.

The idea that machinery can acquire vitality dates back to the Middle Ages. In one of Jules Verne's stories, based on a mediæval legend, a watchmaker of Geneva is supposed to imprison his own soul in the cases of the watches, which palpitate like living flesh. The works are regulated by the pulsation of his own heart, and they run down as the old man's life draws to an end. On the other hand, it is the fear that machinery will acquire an independent existence, and powers inimical to the happiness of mankind, that causes the community in "Erewhon" to destroy all mechanism whatsoever. This most original conception is given stability by an amazing fertility of reason. All the arguments in favour of the ultimate development of mechanical consciousness are marshalled in imposing order. The fact of machines possessing little consciousness now, is shown to be no security against their acquisition of it. A mollusc has not much consciousness. The writer points out that machines are gradually acquiring new organisms. "The plough, the spade, the cart, must feed through man's stomach," but now there are many machines "that have stomachs of their own, and consume the food themselves." This "Book of the



THE FLYING SHIP OF JULES VERNE ("THE CLIPPER OF THE CLOUDS").

Machines" finds a remarkable, indeed a suspicious, parallel in one of the Essays of "Theophrastus Such." The author of "Erewhon" and George Eliot treat the difficult problem of reproduction in almost similar fashion:—

> "What I would ask you is, to show me why . . . there should not at length be a machine of such high mechanical and chemical powers that it would find and assimilate the material to supply its own waste, and then, by a further evolution of internal molecular movements, reproduce itself by some process of fission or budding?"
>
> *Theophrastus Such.*

In "The Coming Race," Bulwer Lytton takes an opposite and more ordinary view. He visions machinery almost sentient, but obedient to the dictates of man. All domestic service in his book is performed by automata; the point is, however, not at all laboured, and the writer is rather occupied with the motive force that drives the mechanism, than with the mechanism itself. This force, to which he gives the name of "Vril," is a kind of exaggerated electricity, and includes magnetism and galvanism; it is of so potent a character that a heap of metal may almost be said to live and reason when subdued to its influence.

The machines in "Erewhon" are supposed to belong to the past; the machines in "The Coming Race" belong to the future. Rudyard Kipling treats of machines as they are at the present moment. But while the vitality of the mechanism in "Erewhon" is no more than a vague foreshadowing, and the automata of "The Coming Race" lack all initiative, Rudyard Kipling's locomotives and steamships have a robust, individual life, at once palpitating and convincing. Think of the stupendous imagination, the almost abnormal sympathy, that can endow with separate entities five or six locomotives in a Round House! The talk goes on as easily and humorously as among the Kipling men; but each phrase is redolent of mechanism, and here a word and there a word betrays the locomotive. If *·007* is a triumph in characterisation, "The Ship that found Herself" is a triumph in conception; present-day machinery has indeed in Mr. Kipling its one supreme interpreter. It is interesting to turn from the ordinary familiar mechanisms he treats of to the invented machines of other writers — so much more marvellous in formation—so much less marvellous in character.

From a study of these we may discover the one great ambition of mankind: the ambition to fly. There are more flying machines in fiction than all the machines of every other kind put together. In this instance, fiction would seem to constitute itself an accurate echo of the world of science, which almost every year claims its roll of martyrs to the art of flying. Already the shadow of an adequate flying machine is palpitating on the air of

actuality. One proof of the mass of statistical matter that has grown round this subject is to be found in the extreme detail with which fictional flying machines are described.

Here is no case for gigantic effort of imagination; writers have merely to take the designs as they stand, to elaborate them a little, to explain away some insignificant point of difficulty, to employ some untried force or some new material, and behold! their characters are able to soar away with the most delightful ease into the empyrean! The Clipper of the Clouds is so minutely described by Jules Verne, that to build it appears by no means impossible; and among all H. G. Wells's vague mechanical contrivances, the only ones of clear definition are the aëroplanes and the aëropiles in "When the Sleeper Wakes."

THE AËROPLANES OR FLYING MACHINES OF H. G. WELLS ("WHEN THE SLEEPER WAKES").

These two writers utterly ridicule the idea that flying machines should be made on the balloon, or "lighter-than-air" principle; their constructions are massive and heavy, and resemble in many respects our sailing vessels. The latest experimenter in flying machines, Count Zeppelin, has reverted to the balloon system; his cigar-shaped cylinder, 300 ft. long, is composed of seventeen sections, each containing a small balloon. In fiction, Bulwer Lytton, who endows his Coming Race with mechanical wings, is obliged to inflate with air a tubular lining beneath the vest or tunic of the flyer; but in his flying machines, or air boats, there is no balloon arrangement—these are driven by helm and rudder, with large wings as paddles. H. G. Wells gives his aëroplanes enormous sails, but Jules Verne dispenses with sails altogether. Both these last-named writers are agreed as to the

LORD LYTTON'S CONCEPTION OF FLYING MACHINES AND MECHANICAL WINGS ("THE COMING RACE").

one and only method of propulsion—the screw.

In the Clipper of the Clouds, one series of screws holds the machine suspended in the air, while another series drives it along. The screws are disposed as a helix, instead of as a paddle-wheel. "The helix advances in the direction of its axis. Is the axis vertical? Then it moves vertically. Is the axis horizontal? Then it moves horizontally." H. G. Wells's aëroplane has a big aërial screw behind. The engine of his aëropile is like the engine of our own days, of the explosive type, burning a small drop of a substance called "fomile" at each stroke. It consists simply of a reservoir and piston about the long fluted crank of the propeller-shaft.

Let us consider the flying machines in further detail.

The Clipper of the Clouds has a framework 100 ft. long and 12 wide—a ship's deck, in fact. Above the deck rise 37 vertical axes, 15 along each side, and 7 more elevated in the centre. Each of these masts bears 2 horizontal screws.

"Each of these axes had its movement independent of the rest, and each alternate one spun round in a different direction from the other, so as to avoid any tendency to gyration. Hence the screws as they rose on the vertical column of air retained their equilibrium by their horizontal resistance. . . . In fact, the vessel combined the systems of Cossus, La Landelle, and Ponton d'Amécourt, as perfected by Robur."

The driving force of the Clipper is electricity, obtained from piles and accumulators. The elements of these piles and the acids employed are, however, secret!

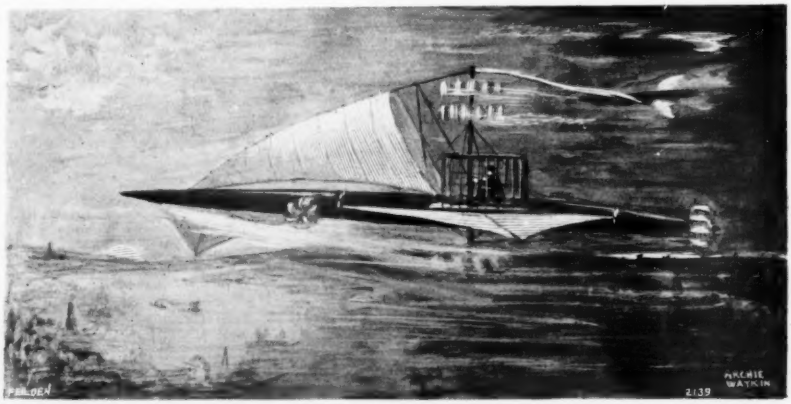
The most original point in this conception is the material of which the machine is composed. It is made of straw-paper, turned hard as metal by compression, and incombustible. The different parts of the engines and screws are composed of gelatinised fibre. For so elaborate a construction, the doings of this machine are rather tame and disappointing. Its speed is only 120 mls. an hour, and its author can invent no more exciting destiny for it than an uneventful cruise round the world.

The aëroplane of H. G. Wells is ten times as long—1,000 ft.—and the stretch of wing 600 ft., or more. The lightly-swung car is from 100 to 150 ft. in length.

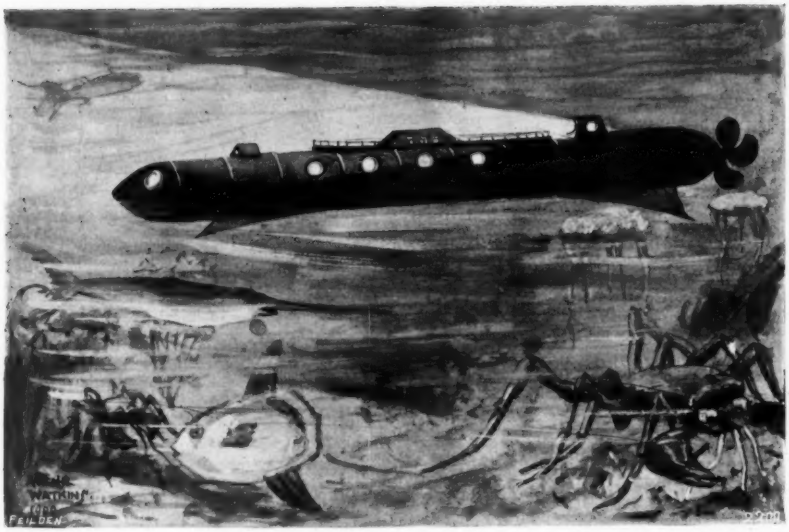
This mechanism has to be started from a gigantic car on the rail of a specially constructed stage. The briefest journey, from London to Paris, takes about three quarters of an hour. Readers will notice many points of resemblance to Maxim's latest invention. Mr. Wells's machine is supposed to be in use some 200 years hence, when London is covered in with a glass roof; and the flying-stages are high above the roof-spaces, and are constructed of that compound of aluminium and iron which has replaced iron in architecture.

The little aëropiles are much more graceful machines. They are built of aluminium—the metal actually used by Count Zeppelin—and the framework is about the size of a 20-ton yacht. Their lateral sails are made of some glassy artificial membrane, brightly coloured, braced and stayed with metal nerves, almost like the nerves of a bee's wing. The chairs of engineer and his passenger are hung within the protecting ribs of the frame. The aëropiles are thrown into the air by a special sort of swift car. These machines are much easier of manipulation than the gigantic aëroplanes; and one man in an aëropile is able to shatter two aëroplanes carrying large numbers of negroes to the loot of London, and to put the rest of the aëroplane army to temporary flight, thus giving the Londoners time to mount their guns upon the roof spaces.

The very clumsiness of the aëroplanes lends them conviction. They are little more than the foreshadowings of scientists. Not so the Time machine. This is, indeed, an eagle flight of imagination. The conception would seem to belong rather to the domain of metaphysics than to the domain of mechanics: it is based on the supposition that there is a fourth dimension—duration—in addition to the three dimensions of length, breadth, and height. "Can an *instantaneous* cube exist?" asks the Time Traveller, and he takes an illustration from an ordinary barometer chart. "Surely the mercury did not draw this line in any of the dimensions of space generally recognised?" He concludes that it was traced along the time dimension, and acting on this reasoning, he constructs a machine that will travel through Time. The machine is not described with any great detail; indeed, over-elaboration would only serve to emphasise the impossibility of the conception, which, involved in vagueness, becomes almost credible. We are told that parts of the machine are of nickel, parts of ivory, and parts of rock-crystal. It has a twisted crystalline bar, with an odd twinkling appearance, which seems to be made of quartz. The machine is singu-



"THE TIME MACHINE" (H. G. WELLS).



JULES VERNE'S SUBMARINE BOAT ("TWENTY THOUSAND LEAGUES UNDER THE SEA").

larly askew. One lever, being pressed over, sends the machine gliding into the future, and another reverses the motion. This is indeed a fairy thing, with no reasons assigned either for its materials or mode of construction: it belongs to the domain of the poet rather than to the domain of the engineer; but it is a fact that Mr. Wells has never approached in any of his other works the striking originality of the conception of the time machine.

Before leaving the fictional flying machines, it may be well to glance at the projectile inventions of novelists for covering immense distances. It is by means of projectiles that earth-dwellers reach the moon—by means of projectiles that Martians reach the earth. Jules Verne even goes so far as to say that the projectile will be the motion of the future, and foretells the time when we shall run projectile trains to our satellite! His projectile, being built by men on earth, is described in much fuller detail than Mr. Wells's projectile from Mars. Both of these, however, are projected by some kind of explosive, and both are originally cylindrical in shape, though Jules Verne afterwards alters his to cylindro-conical form. The Martian cylinders have a diameter about thirty times as great as the projectile built by the Gun Club at Baltimore. Here are the details of Jules Verne's projectile:—

The projectile is a shell made of aluminium, with a diameter of 108 ins., and a thickness of 12 ins. to its walls; it weighs 19,250 lbs.

The gun is a Columbiad cast in iron 900 ft. long, and run perpendicularly into the earth. The charge contains 400 000 lbs. of gun-cotton.

With regard to the cylinders of the Martians, we are only told that they are composed of some unknown yellowish-white metal, and covered by a thick, scaly, dun-coloured incrustation which is no common oxide. They have tops that unscrew.

But of all the cylinders of fiction, not the cylinders that explore space, but the cylinder that goes 20,000 leagues under the sea, was dearest to our youthful imagi-

nations. No machine invented since has has equalled in wonder and magic the *Nautilus* with its mysterious Captain Nemo. It is surprising to find with what extraordinary wealth of detail the *Nautilus* is constructed. To summarise briefly :—

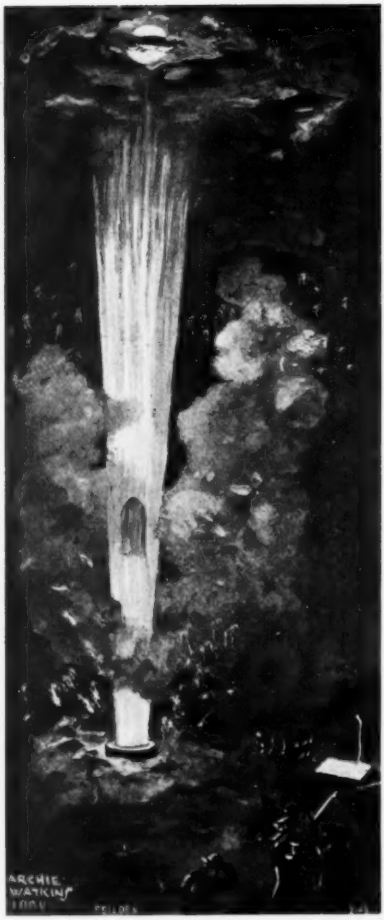
It is an elongated cylinder with conical ends. The length of the cylinder, from stem to stern, is exactly 232 ft., and its maximum breadth is 26 ft. It is composed of two hulks, one inside, the other outside, joined by T-shaped irons, which render it very strong. These two hulks are composed of steel plates, whose density is from ·7 to ·8 that of water. The first is not less than 2½ in. thick, and weighs 394 tons. The second envelope, the keel, 20 in. high, and 10 in. thick, weighs alone 62 tons.

The *Nautilus* is lighted, warmed, and worked by electricity, which is obtained from sodium extracted from salt water. Jules Verne seems in his *Nautilus* to have anticipated on many points the French submarine boat, the construction of which, however, is involved in considerable mystery.

Jules Verne has enunciated no new mechanical principles; his machines are simply a little in advance of those of our day. H. G. Wells, on the contrary, not only seeks to represent the era when the extreme limit of the perfectibility of machinery has been reached; he also sets forth some entirely novel theories in regard to mechanics. The most interesting of these concerns itself with the absence of the wheel—the dominant feature of almost all human devices—in Martian machinery. Mr. Wells points out the curious fact that nature has never hit upon the wheel :—

> Not only did the Martians not know of (which is incredible) or abstain from the wheel, but in their apparatus singularly little use is made of the fixed pivot, or relatively fixed pivot, with circular motions thereabout confined to one plane. Almost all the joints of the machinery present a complicated system

MARTIAN FIGHTING MACHINES ("THE WAR OF THE WORLDS," H. G. WELLS).



"FROM THE EARTH TO THE MOON" (JULES VERNE).

of sliding parts, moving over small but beautifully curved friction-bearings. And, while upon the matter of detail, it is remarkable that the long leverages of their machines are in most cases actuated by a sort of sham musculature of discs in an elastic sheath; these discs become polarised, and drawn closely and powerfully together when traversed by a current of electricity. In this way the curious parallelism to animal motion . . . was attained.

The Martian fighting machines, some 100 ft. high, are monstrous tripods on which machinery is mounted. Each of them carries a Martian. Their motion is described as resembling "a milking stool, tilted and bowled violently along the ground." Is it the difficulty of inventing a wheelless machine that makes these, and the other Martian machines, so almost impossible of realisation?

"When the Sleeper Wakes" chronicles no advance in chemistry; machinery, however, has become more perfect, and a hideous nightmare is the result. London two hundred years hence, roofed in, artificially lighted night and day, with its cables, its suspension bridges, its moving platforms, is infinitely baser and more miserable than the city of to-day. All the little trivial toys of our science have become by that time of supreme importance: the kinetoscope and the phonograph, for instance, have replaced the book and the schoolmaster. We are inclined to think that a certain section of our Press has reached the lowest depth of vulgarity and sensationalism; but the appalling babble machines reveal one lower.

And what have we to set against this terrible picture of the future of machinery? It is a remarkable fact that no novelist, approaching this subject in a philosophic spirit, can find reason to hope for any increased happiness to mankind through the improvement of machinery. Bulwer Lytton is the one exception, and his beings have practically lost all understanding of art.

Perhaps we stand too near to machinery to see it in due perspective; we lack the pre-vision of modifying possibilities. Rudyard Kipling is our one writer who has keen perception of the delicate accuracies, the exquisite reliability of mechanical contrivance. Why does he not give us a joyous romance of its future?

Ethel Wheeler.